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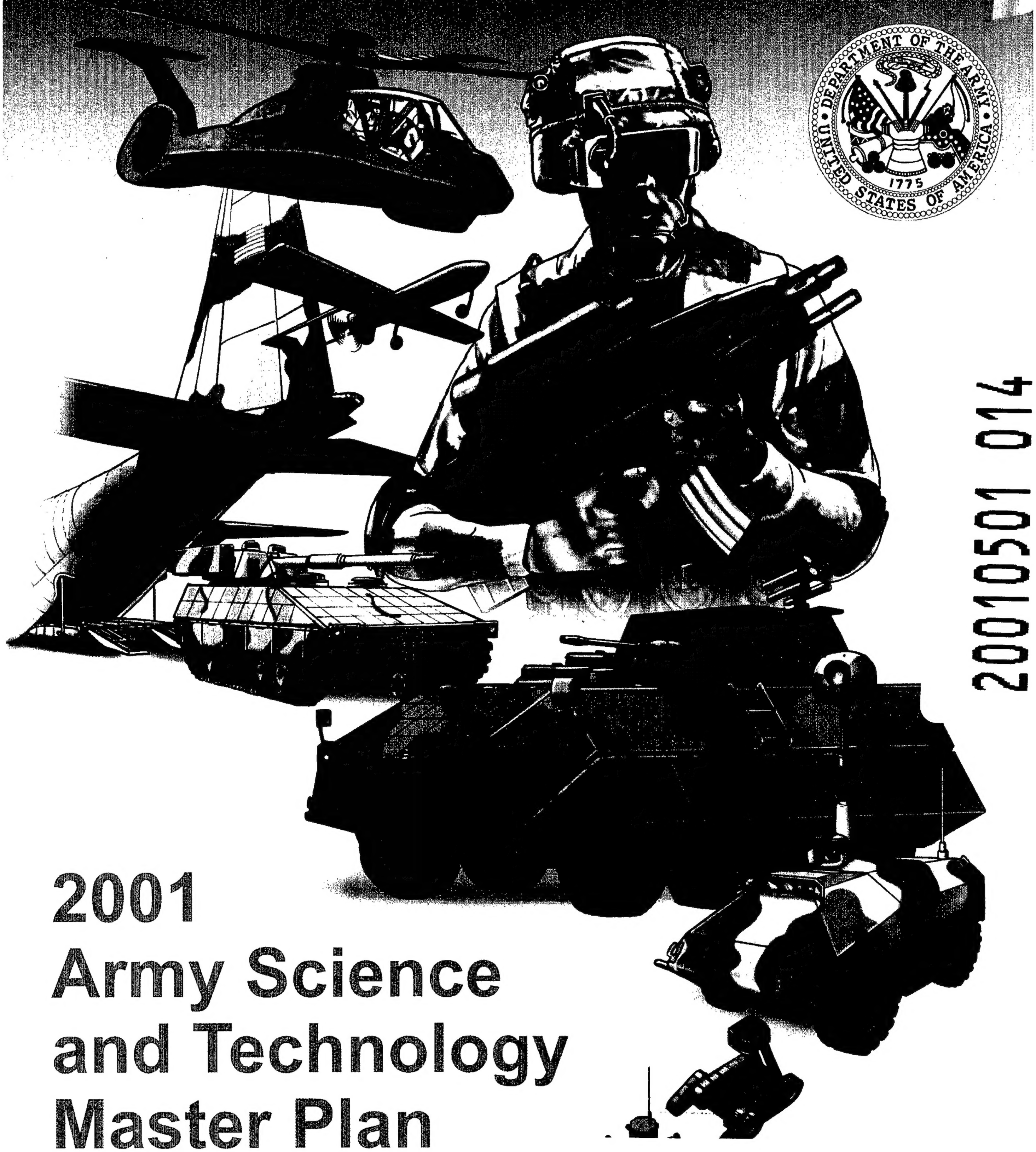

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2001 Army Science and Technology Master Plan

VOLUME II Annexes

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ARMY SCIENCE AND TECHNOLOGY MASTER PLAN 2001

ANNEXES

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VOLUME II, ANNEXES

ANNEX

A SCIENCE AND TECHNOLOGY OBJECTIVES

CONTENTS

ANNEX

A SCIENCE AND TECHNOLOGY OBJECTIVES

PURPOSE

To provide guidance to the science and technology (S&T) community, the Army establishes a set of Science and Technology Objectives (STOs), each of which states a specific, measurable, major technological advancement to be achieved by a specific fiscal year. The STOs are consistent with the funding available in the current year budget, the Future Years Defense Plan (FYDP), and the Program Objective Memorandum (POM). The Army uses these STOs to focus and stabilize the 6.2 and 6.3 programs, practice management by objectives, and provide feedback to its scientists and engineers regarding their productivity and customer satisfaction. Annex A is comprised of four sections: (1) Advanced Technology Development STOs (Chapter III), (2) Applied Research STOs (Chapter IV), (3) Technology Readiness Level (TRL) table, and (4) STO-to-Defense Technology Objective (DTO) mapping.

The STO descriptions in this annex are organized following the taxonomy of Chapters III and IV of Volume I. The numbering convention of the STOs is as follows:

Chapter (e.g., III)
Tech Area (e.g., AV)
FY Approved as a STO (e.g., 2000)
Sequence Number (e.g., 02)

For example, III.AV.1998.01 is the STO number for Helicopter Active Control Technology. The technology area designations are defined in the following tabulation.

Technology Area	Code	Technology Area	Code
Aviation	AV	Chemical/Biological Defense	BC
Command, Control, Communications, and Computers	C4	Air and Missile Defense	AD
Intelligence, Surveillance, and Reconnaissance and Electronic Warfare	IS	Engineering, Combat Construction, Mobility, and Countermobility	EN
Electronic Warfare	EW	Logistics	LG
Ground Combat and Tactical Systems	GC	Personnel Performance	PE
Weapons	WP	Space	SS
Soldier Systems	SH	Materials, Material Processes, and Structures	MA
Soldier and Personnel Technologies	SP	Sensors and Electronics	SN
Biomedical	ME	Battlespace Environment	BA

The STOs identify three points of contact (POCs). The first POC is the ASA(ALT) Technical Staff Officer (TSO). Next is the TRADOC POC representing a battle lab, a division in TRADOC Combat Developments, or a TRADOC Systems Manager (TSM). The third POC is the lead STO Manager. Organization and commercial and defense systems network (DSN) telephone numbers for each POC are provided.

ADVANCED TECHNOLOGY DEVELOPMENT (TECHNOLOGY TRANSITION) (CHAPTER III, VOLUME I)

AVIATION

III.AV.1996.01—HELICOPTER ACTIVE CONTROL TECHNOLOGY (HACT). This STO demonstrates a 50 percent reduction in the probability of degraded handling qualities due to flight control system failures; a 60 percent improvement in weapon pointing accuracy; a 50 percent increase in agility and maneuverability; and a 30 percent reduction in flight control system flight test development time. HACT will demonstrate integrated, state-of-the-art rotorcraft flight control technologies with exploitation of advanced fixed-wing hardware components and architectures. The objective is to demonstrate, through simulation and flight test, second-generation rotorcraft digital fly-by-wire/light control systems with fault-tolerant architectures, including carefree maneuvering, task-compliant control laws, and integrated fire/fuel/flight control capabilities, designed with robust control law design methods. The program will overcome technical barriers such as the lack of knowledge of optimal rotorcraft response types; inadequate techniques for sensing the onset of envelope limits, cueing the pilot, or limiting pilot inputs; inadequate air vehicle math modeling for high-bandwidth flight control; inadequate flight control system design, optimization, and validation techniques; and lack of knowledge in the optimum functional integration of flight control, weapon systems, and pilot interface. Payoffs of the HACT program will include capability improvements in all-weather/night mission performance, flight safety, and development time/cost that contribute to a 4 percent reduction in RDT&E costs, a 65 percent increase in maneuverability/agility, and a 20 percent reduction in the major accident rate.

In FY99, completed hardware and software preliminary design. In FY00, fabricated hardware and performed software verification and validation (V&V) and hardware-in-the-loop (HITL) simulation. By FY02, integrate flight control system with flight test vehicle (TRL 7).

Supports: Future Transport Rotorcraft (FTR), RAH–66 Comanche, AH–64 Apache, DoD rotorcraft system upgrades.

TSO	TRADOC POC	STO Manager
Mary Miller	Ted Hundley	Bob Buckanin
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–1465	(757) 878–4371
329–1543	558–1465	927–4371

III.AV.1996.02—AIR/LAND ENHANCED RECONNAISSANCE AND TARGETING (ALERT) ATD. This program demonstrates on-the-move (OTM) automatic aided target acquisition and enhanced identification via a second-generation, forward-looking infrared (FLIR)/multifunction laser sensor suite for application to future aviation and ground assets that do not have radar. ALERT will leverage ongoing Air Force and Defense Advanced Research Projects Agency (DARPA) developments for search OTM automatic target recognition (ATR), including the use of temporal FLIR processing for moving target indicator (MTI). This approach will also enable application of the ATR capability to all weapon systems with integrated FLIR/laser sensors. The demonstration will be a real-time, fully operational flying testbed emulation of all modes of the basic RAH–66 target acquisition system (TRL 6).

In FY98, demonstrated baseline OTM performance using second-generation FLIR and standard range-finding mode (TRL 3). In FY99, integrated laser range mapping capability to demonstrate OTM aided target acquisition with acceptable false alarms as a lower cost alternative to FLIR/radar fusion. In FY00, integrated laser profiling capability to demonstrate automatic acquisition and identification

Supports: MBSBL, D&SABL, BCBL, EELSBL, RAH–66 Comanche, AH–64C/D Apache.

TSO	TRADOC POC	STO Manager
Rob Saunders	Ted Hundley	Maurice Cook
SAAL–TT	USAAVNC	CERDEC/NVESD
(703) 601–1546	(334) 255–1465	(703) 704–1059
329–1546	558–1465	654–1059

III.AV.1997.01—ROTARY-WING STRUCTURES TECHNOLOGY (RWST). This program fabricates and demonstrates advanced, lightweight, tailorable structures and ballistically tolerant airframe configurations that incorporate state-of-the-art computer design/analysis techniques, improved test methods, and affordable fabrication processes. The technology objectives are to increase structural efficiency by 15 percent, improve structural loads prediction accuracy to 75 percent, and reduce costs by 25 percent without adversely impacting airframe signature.

In FY98, developed and demonstrated manufacturing process feedback algorithms to actively control the cure state of composite resins to reduce problems with porosity, degree of cure, and fiber volume fraction. In FY99, demonstrated fully composite primary structural joints to reduce the manufacturing labor for large composite components; increased the structural efficiency; and provided validated strength and fatigue life methodologies for rotorcraft composite structures. In 2000, demonstrated adaptive, out-of-autoclave tooling with preferential heating to optimize the cure cycle of co-cured composite elements of highly variable thickness; and exploited emerging technologies in nondestructive inspection, miniature sensors for manufacturing process control, and modeling/virtual prototyping for reducing development time and cost. By FY01, demonstrate advanced airframe sections that are tailored for structural efficiency, affordably producible, and field supportable (TRL 6). These goals support the systems payoffs of 55 percent increase in range or 36 percent increase in payload, 20 percent increase in reliability, 10 percent improvement in maintainability, 6 percent reduction in RDT&E costs, 15 percent reduction in procurement costs, and 5 percent reduction in O&S costs for utility-type rotorcraft.

Supports: Primary emphasis provides technology options to the UH–60, AH–64, Improved Cargo Helicopter (ICH), RAH–66, and Special Operations aircraft (SOA) upgrades; future air vehicles (e.g., FTR; collaborative technology; and operational capability requirements (OCRs) for EELSBL, CSSBL, D&SABL, DBBL, and Mounted Battle Lab (MTDBL)). Contributes to rotary-wing vehicle (RWV) technology development approach (TDA) objectives, goals, and payoffs.

TSO	**TRADOC POC**	**STO Manager**
Mary Miller	Ted Hundley	Gene Binocco
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–1465	(757) 878–5609
329–1543	558–1465	927–5609

III.AV.1998.01—INTEGRATED SITUATION AWARENESS AND TARGETING (ISAT) ATD. This STO demonstrates horizontal technology integration (HTI) radio frequency (RF), missile and laser warning upgrades to the suite of integrated radio frequency countermeasures (RFCM) (AN/ALQ–211), CMWS (AN/ALQ–212), and Laser Warning Receiver (AVR–2A, VVR–1) that provide precision hostile situation awareness, target acquisition, geolocation, and combat identification (CID) assistance for active emitters. Radar warning will be upgraded to provide a 10X improvement in target detection, and geolocation to an accuracy of 100 m at 10 kilometers (km). Fusion of pre-flight and real-time command, control, communications, and intelligence (C^3I) links with onboard emitter fingerprinting will provide enhanced CID information to meet rules of engagement and allow weapon release at maximum ranges. Real-time bidirectional command, control, communications, computers, and intelligence (C^4I) feeds to the digitized battlefield will provide ground commanders and vehicles with targeting feeds from combined arms systems equipped with ISAT capability.

In FY99, integrated digital and HITL models into the Communications–Electronic Command (CECOM) Survivability Integration Laboratory (SIL)/Digital Integration Laboratory (DIL). In FY00, conducted real-time distributed interactive simulation (DIS) experiments with Fort Rucker's cockpit simulator, Ft. Knox's mounted testbed, and Ft. Sill's targeting testbed that focus on real-time targeting and enhanced situation awareness for operations OTM (TRL 4). By FY01, integrate radar and missile warning receiver upgrades, and complete optimization of data fusion, operator situation awareness displays, and C^4I datalinks via real-time air/ground crew station SIL/DIL experiments. By FY02, complete aircraft integration and testing, final report, and transition to the Program Manager—Aviation Electronic Systems (PM–AES) (TRL 6).

Supports: PM–AES.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	Ted Hundley	Steven Oshel
SAAL–TT	USAAVNC	CERDEC/I2WD
(703) 601–1546	(334) 255–1465	(732) 427–3936
329–1546	558–1465	987–3936

III.AV.1998.03—INTEGRATED COUNTERMEASURES (ICM). This STO demonstrates new multispectral RFCM, IRCM, and electro-optic (EO) countermeasures (EOCM) techniques and device upgrades that will provide Army aviation and ground vehicles with full-dimensional protection to enable maneuver on the battlefield. The AN/ALQ–211 and AN/ALQ–212 PM–Aviation Electronic Systems (PM–AES) systems will be upgraded with advanced jamming modulators and algorithms to provide a family of configurable air and ground vehicle countermeasure modules. This program will provide countermeasures that provide greater than 99 percent probability of survival-per-mission to multisensor IR/EO/RF and laser homing missiles, antitank guided missiles (ATGMs), and top-attack smart munitions. This program will demonstrate a 50 percent reduction in installed sensor and A-kit weight; a 200 percent increase in mean time between failure (MTBF); and fiber-optic, remoted, low-cross-section RF antennas/transmitters.

In FY99, demonstrated integration of digital and HITL jamming effectivity models of advanced imaging IR SAMs and double-digit RF SAM system, under development by MSIC, into the CECOM SIL/DIL. In FY00, completed DSI integration of AATD's signature models into CECOM's Fort Rucker's cockpit simulator and Ft. Knox's mounted testbed (TRL 4). By FY01, conduct real-time, interactive air/ground cockpit digital modeling and simulation (M&S) and HITL SIL testing. By FY02, complete flight and ground vehicle testing; final report; transition to PM–AES's AN/ALQ–211 and AN/ALQ–212 system development and demonstration (SDD) update program; and CAGES demonstration (TRL 6).

Supports: PM–AES, PEO–IEW&S.

TSO	TRADOC POC	STO Manager
Rob Saunders	Ted Hundley	Ray Irwin
SAAL–TT	USAAVNC	CERDEC/I2WD
(703) 601–1546	(334) 255–1465	(732) 427–4589
329–1546	558–1465	987–4589

III.AV.1998.04—INTEGRATED HIGH-PERFORMANCE TURBINE ENGINE TECHNOLOGY (IHPTET) JOINT TURBINE. IHPTET is a three-phased tri-service/DARPA/NASA effort to double U.S. turbine engine performance capability by 2003. The goal is to develop a tri-service Joint Turbine Advanced Gas Generator (JTAGG) to demonstrate performance goals consistent with the IHPTET initiative for the turboshaft/turboprop class of engines, and to initiate the third phase of the JTAGG program.

In FY00, completed testing of JTAGG–III technologies. By FY03, effectively double the propulsion system capability through demonstration of a 40 percent reduction in specific fuel consumption, a 120 percent increase in shaft horsepower (Shp)-to-weight ratio, and a 35 percent reduction in production and maintenance costs. Demonstrate emerging technologies related to IHPTET goals in the areas of structures, controls, aerodynamics, advanced materials, and accessories that provide reduced vulnerability, improved reliability and maintainability, and high levels of readiness and mission success (TRL 7).

Supports: Precision Strike, Advanced Land Combat, Technology for Affordability, RAH–66 Comanche; AH–64 Apache improvement, FTR, and system upgrades; AMBL, MSBL, EELSBL, D&SABL, MBSBL, CSSBL; dual-use potential.

TSO	TRADOC POC	STO Manager
Mary Miller	Ted Hundley	Sandra Hoff
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–1465	(804) 878–4130
329–1543	558–1465	927–4130

III.AV.1999.01—AIRBORNE MANNED/UNMANNED SYSTEM TECHNOLOGY DEMONSTRATION (AMUST–D). This program demonstrates through simulation and flight-tests the control mechanisms, intelligent linkages, and integration architectures to allow a manned aerial vehicle (MAV)/UAV system to operate as an effective warfighting system of systems to increase the combined arms team's battlefield effectiveness. AMUST–D will provide effectiveness and synergy over current battlefield systems that will allow a 25 percent increase in operational efficiency, 35 percent increase in operational effectiveness (tactical and short dwell; i.e., perishable targets), 50 percent reduction in hunter-to-shooter timelines, and 25 percent increase in survivability of the manned system.

In FY00, addressed the technical barriers associated with manned/unmanned teaming and defined the AMUST system (TRL 4). By FY01, develop the hardware and software for system demonstration. By FY02, demonstrate system performance through simulation (TRL 5). By FY03, demonstrate system performance through flight test of the AMUST team (TRL 7).

Supports: Future operational capabilities (FOCs) AD97–004, AD97–007, AR97–001, AV98–004, AV98–005, AV98–007, AV98–011, DSA97–001, DSA97–018, DSA97–024, DSA97–025, DBS97–016, DBS97–064, DBS97–066, EN98–011, FA98–006, FA98–007, FA98–012, FPC98–06, MMB97–015, MMB97–019, MSB97–014, SP98–011, TC98–005; AH–64D and RAH–66 upgrades; UAV and Tactical Control System developments; AMBL, CEP, and other services.

TSO	TRADOC POC	STO Manager
Mary Miller	Glenn Harrison	Keith Arthur
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–3203	(757) 878–2772
329–1543	558–3203	927–2772

III.AV.1999.02—MODERNIZED HELLFIRE (MHF)/COMMON MISSILE (CM). The MHF technology effort will address seeker and propulsion technologies (incorporating multimode applications (i.e., ground-to-ground missions in support of Common Missile as well as the traditional Hellfire/Longbow air-to-ground missions). The MHF program leverages missile technology being developed in support of the beyond-line-of-sight (BLOS) Networked Fires (NetFires) program. In addition, this effort supports the new Army vision of lighter, more lethal weapon systems contained on the Future Combat Systems and Common Missiles.

By the end of FY01, detailed seeker design and propulsion component development will be complete. By the end of FY02, fabricate and tower test the seeker design and complete breadboard propulsion system. By the end of FY03, conduct captive flight test for the seeker, conduct propulsion flight-type static test and transition these technologies for insertion in an EMD program in FY04 (TRL 6). The test data and technical maturity of these technologies will be used to validate on-going system integration efforts largely sponsored by the PEO—Tactical Missiles. The development of these technologies and associated system integration efforts are part of a joint AMRDEC/PEO—Tactical Missile MHF/CM Program designed to achieve Milestone C/EMD decision based on the new acquisition methodology, simulation-based acquisition.

Supports: Army Aviation Director of Combat Developments (DCD), Apache, Comanche, PM–ARM, Marines.

TSO	TRADOC POC	STO Manager
Mary Miller	COL Jesse Danielson	Greg Haynes
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–3203	(256) 842–8772
329–1543	558–3203	788–8772

III.AV.1999.03—LOW-COST PRECISION KILL (LCPK) 2.75-INCH GUIDED ROCKET ATD. This LCPK STO will demonstrate a low-cost (<$10,000), accurate (1-m circular error probable (CEP)) 2.75-inch guided rocket that provides a standoff-range (6 km), surgical-strike capability against specified soft point targets. Using a small, strapdown laser seeker, off-the-shelf inertial devices, and a low-cost control mechanization, the LCPK guided rocket will achieve a high single-shot probability of kill (P_k), reducing cost/kill by 2X–4X, minimizing collateral damage, and increasing the number of stowed kills by 4X–20X.

In FY99, demonstrated a stable airframe with 90 percent reduction in guidance section spin rates via wind tunnel and ballistic flights. In FY00, demonstrated a 10X reduction in 2.75-inch rocket dispersions via control test vehicle (CTV) flights. By the end of FY01, demonstrate approximately 1-m CEP accuracy via guided test vehicle (GTV) flights from ground, and complete AH–64 aircraft integration (TRL 6). By the end of FY02, complete GTV flights from the AH–64 aircraft and initial qualification (TRL 7).

Supports: Apache, Comanche, Special Operations Forces (SOF), Marines.

TSO	TRADOC POC	STO Manager
Mary Miller	COL Jesse Danielson	Bill Nourse
SAAL–TT	USAAVNC	AMCOM AMRDEC
(703) 601–1543	(334) 255–3203	(256) 876–7384
329–1543	558–3203	746–7384

III.AV.2000.01—ADVANCED NIGHT VISION GOGGLES (ANVG) ATD. The focus of this program is to develop and demonstrate the Air Warrior ORD requirement for an integrated 100-degree field of view (FOV) helmet-mounted night vision goggle system. The ANVG will significantly improve the aviator's safety of

flight, situational awareness, and night pilotage capabilities under adverse weather and military operations in urban terrain (MOUT) conditions. The ANVG will provide an ultra-wide 40-degree × 100-degree FOV with better than 50 percent resolution improvement over current average, and an integrated head-up display for aircraft symbology. Low halo tube technology will provide more effective navigation and improved safety in MOUT operations. The ANVG will be a modular horizontal technology integration (HTI) design that can also meet requirements for Mounted Warrior and Land Warrior (LW), allowing head mounting for night driving, navigation, or handheld weapon usage. Additionally, for the dismounted application, an uncooled or short-wave infrared (SWIR) FLIR camera will be added to the helmet-mounted assembly that will provide thermal image insert to the image intensifier to enhance target detection performance and complement the I2 performance.

In FY00, performed a human interface study with HRED and ARL, completed system design, initiated uncooled or SWIR FLIR design tradeoffs, and conducted I2 tube process development. TRL 4) By FY01, complete I2 tube development with 20/30 high-light-level and 20/85 low-light-level resolution for integration into system (TRL 5). By FY02, conduct user flight evaluations and qualification of the critical I2 tube and transition to PM–NV/RSTA for SDD/LRIP program; conduct user assessment of performance–human interface/cost tradeoffs for reduced FOV configurations for ground applications. Adapt FLIR camera development for dual-spectrum sensor capability (TRL 5/6). By FY03, complete FLIR camera integration and conduct ground user assessment tests (TRL 7).

Supports: PM–NV/RSTA, USA Aviation Center, USA Armor Center, USA Infantry Center, AMBL, DBBL, MBBL, PM–Aircrew Integrated Systems (PM–ACIS), PM—Air Warrior, FCS vehicle commander.

TSO	TRADOC POC	STO Manager
Rob Saunders	COL Danielson/COL Kinnison	Elliott Lloyd
SAAL–TT	USAAVNC, USAAC/TSM Soldier	NVESD
(703) 601–1546	(334) 255–3203/(706) 545–1189	(703) 704–1250
329–1546	558–3203/835–1189	654–1250

III.AV.2001.01—ROTORCRAFT DRIVE SYSTEMS FOR THE 21ST CENTURY (RDS–21). This program demonstrates a major advancement in drive system technology for large rotorcraft, such as FTR, through the application of emerging technologies in materials, structures, mechanical components, dynamics, acoustics, lubrication, and manufacturing processes. RDS–21 will attack essential technical challenges currently limiting the performance and affordability of large rotorcraft drive systems. Specific objectives of RDS–21 are a 35 percent increase in power-to-weight ratio, a 25 percent decrease in operating costs ($/FH), a 15-dB decrease in noise, and a 25 percent decrease in production cost.

By the end of FY02 and FY03, complete preliminary and detailed design, respectively. The design will use advanced component technologies with very high reduction ratios, high efficiency, and minimum number of components. Advanced design codes will be applied to shorten development time and optimize performance and durability (TRL 4). By the end of FY04, complete fabrication of test hardware, representative of a major large rotorcraft drive system. Conduct performance, endurance, noise, and damage tolerance testing in a test stand capable of applying design loads and simulating the expected environmental conditions (TRL 5). By the end of FY05, use test results to validate both the achievement of the RDS–21 goals and the accuracy of the design codes (TRL 6).

Supports: Potential application to AH–64, UH–60, RAH–66, and V–22 developments and other service aircraft.

TSO	TRADOC POC	STO Manager
Mary Miller	Ted Hundley	Sandra Hoff
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–1465	(757) 878–4130
329–1543	558–1465	927–4130

COMMAND, CONTROL, COMMUNICATIONS, AND COMPUTERS

III.C4.1997.01—ARMY COMMUNICATIONS INTEGRATION AND COSITE MITIGATION (CICM). This STO reduces the size, weight, and cosite interference problems that occur when multiple radios in either the same or dissimilar frequency bands are integrated within a mobile communications command post (CP) platform. Solutions derived from this STO will be applicable to Army platforms within the Rapid Force Projection Initiative (RFPI) Light Digital Tactical Operations Center (TOC) and other Army platforms, including the BCV, CGS, and future systems using Future Transport Rotorcraft System (FTRS). Technology from the current FTRS development effort and Antennas Across the Communications Spectrum (A^2CS) STO will be coupled with new CICM STO efforts to address the size/weight problem of multiple radio systems within the continuous frequency band from 2 MHz to 2 GHz, and the cosite interference problem in the VHF and UHF bands. New CICM STO efforts include the development of a VHF/UHF multiplexer using cosite mitigation technology, a wideband (2 MHz to 2 GHz) linear power amplifier, and enhancements internal to the future digital radio (FDR) multiband, multimode radio (MBMMR) to improve cosite performance.

In FY98, conducted an initial demonstration with VHF/UHF multiplexers as part of the Light Digital TOC leave-behind, including use of wideband and multiband antennas developed under the A^2CS STO. In FY00, completed development of the wideband power amplifier and FTRS cosite enhancements. A multiband communications system will be integrated within a typical Army single-integration CP shelter mounted on an HMMWV, and tests will be performed to evaluate the resultant performance and enhancements. This testbed is being exercised throughout the FY99–01 period for evaluation of the individually developed items. A final field demonstration and evaluation of all the developed items, plus FTRS and A^2CS STO, will be performed in late FY01 (TRL 6). These efforts are considered a natural extension of the size reduction and waveform reconfigurability goals of the FTRS.

Supports: PEO–C^3S.

TSO	TRADOC POC	STO Manager
Rob Saunders	Martin Bosemer	Steve Goodall
SAAL–TT	DFD, Ft. Knox	CERDEC/S&TCD
(703) 601–1546	(502) 624–2045	(732) 532–0445
329–1546	464–2045	992–0445

III.C4.1997.02—TACTICAL COMMAND AND CONTROL (C^2) PROTECT ATD. This program demonstrates the ability to protect the Army's tactical information systems, components, and data from modern network attacks. The *attack* portion will demonstrate the ability to launch effective C^2 attacks against Integrated Battlefield Area Communication Systems (IBACS) (threat information systems). This ATD will leverage existing COTS and DoD programs that target network security technology. The approach will be to develop tactical network protection and attack capabilities, then use the attack techniques against the protection mechanisms to determine the effectiveness of both. A M&S/simulation environment will be established to support man-in-the-loop (MITL) evaluation and warfighter training for advanced C^2 protect and attack capabilities. Demonstration for the *protect* portion will include an integrated security architecture that provides advanced network access control, intrusion detection, and response within tactical communications networks. The demonstration for the attack portion will be an integrated system that can launch both RF- and wire-based attacks against threat information systems. A security

architecture for the Army's tactical internet will be developed to include a representative LW platform, and initial attack capabilities will be developed and evaluated in the DIL.

In FY99, evaluated attack capabilities against the existing security architecture. The security architecture is being extended to include mobile subscriber equipment (MSE), a field test/demonstration is being conducted for RF attack against attack threat information systems, and the improved protect and attack capabilities are being evaluated against each other. By FY02, revise the security architecture and extend it down to include small-unit operations (SUO); demonstrate an integrated capability for launching RF- and wire-based attacks of threat tactical systems; and develop tactics, techniques, and procedures for field IEW systems (TRL 5/6).

Supports: PEO–C^{3}S, PEO–IEW&S.

TSO	**TRADOC**	**STO Manager**
Rob Saunders	COL Rodger Knox	LTC Kathryn Carlson
SAAL–TT	BCBL(G)	CERDEC/S&TCD
(703) 601–1546	(706) 791–2057	(732) 427–2306
329–1546	780–2057	987–2306

III.C4.1998.01—THEATER PRECISION STRIKE OPERATIONS (TPSO) [STO JPS DEMONSTRATION (JPSD) 01] ACTD. This program develops and demonstrates a significantly improved capability to synchronize, coordinate, deconflict, and employ the deep-strike assets of the Joint Force Land Component Commander (JFLCC) with joint and coalition assets between the forward line of own troops (FLOT) and the forward boundary. This effort will develop a theater Enhanced Deep Operations Coordination Center (EDOCC) with enhanced C^{4}I and strike planning processes to include Army Tactical Command and Control System (ATCCS) enhancements, Global Command and Control System (GCCS) integration, visualization tools, and connectivity with coalition forces. Using the capabilities within his Deep Operations Coordination Center (DOCC), the JFLCC will be able to better use existing systems such as MLRS, Army Tactical Missile System (TACMS), Predator, Close Air Support, and advanced systems such as Guided MLRS, MLRS Smart Tactical Rocket, Navy TACMS, and powered submunitions.

In FY01, the ACTD will culminate in an FY01 OCONUS exercise in a Korean scenario that explores the transition from an unreinforced to a reinforced battle. New concepts demonstrated should allow the JFLCC to defeat 50 percent more threat targets in the first 24 hours than the current capability. Candidate residuals that will permit this improvement include networking U.S. and Korean Firefinders, acoustic sensors, GCCS integration, ATCCS enhancements, and planning software.

Supports: Commander in Chief CINCUNC/CFC, D&SABL.

TSO	**TRADOC POC**	**STO Manager**
Bruce Zimmerman	COL Mitchel Poodry	LTC Rob Pope
SAAL–TT	DBBL	JPSD Project Office
(703) 601–1559	(706) 545–23102	(703) 704–1962
329–1559	835–2310	

III.C4.1999.01—ON-THE-MOVE (OTM) TACTICAL SATELLITE COMMUNICATIONS (SATCOM) TECHNOLOGY. The focus of this program is to develop an OTM SATCOM ground terminal capability that recovers quickly from signal blockages due to man-made objects, terrain/foliage, weather, and other atmospheric effects. These terminals will be used with emerging wideband commercial low-Earth-orbit (LEO) (Teledesic, Celestri, etc.), medium-Earth-orbit (MEO), and military geosynchronous-Earth-orbit (GEO) SATCOM and protected (advanced, extremely high frequency (EHF)) narrowband SATCOM. Technology challenges include the development of fast recovery (from blockages), coding, protocols and antennas. Programmable fast-recovery (from blockages) modems allow use with different satellite constellations.

In FY00, conducted a review of existing and proposed commercial SATCOM technologies and initiated development of a fast-recovery modem for EHF narrowband communications. By FY01, initiate development of a fast-recovery modem for Ka-band LEO/MEO wideband communications (TRL 3). By FY02, validate link layer protocols, including recovery from blockages (TRL 4). By FY03, develop coding, protocols, antennas, and modems to achieve and demonstrate narrowband protected mode OTM SATCOM (TRL 5). By FY04, develop coding, protocols, and modems to achieve wideband communications OTM with MEO, LEO, and GEO satellites, and provide terminals that are small in size, weight, and power consumption. Demonstrate the narrowband protected mode enhancements by FY03, and demonstrate wideband LEO, MEO, and GEO enhancements by FY04, including use of surrogate SATCOM packages (TRL 5).

Supports: PM–MILSATCOM.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	Tom Mims	Tom Nelson
SAAL–TT	BCBL(G)	CERDEC/S&TCD
(703) 601–1546	(706) 791–2800	(732) 427–2339
329–1546	780–2800	987–2339

III.C4.1999.02—BATTLESPACE TACTICAL NAVIGATION (BTN) [HTI STO]. This program develops technology and integration concepts that improve the robustness of navigation systems by minimizing registration errors between sensors and databases. Under the BTN program, Global Positioning System (GPS) signal reception in hostile electronic countermeasures (ECM) environments will be provided by the deployment of ground-based GPS pseudolites and the incorporation of advanced antijam GPS technology (i.e., filters, antennas, low-power clocks). Backup navigation capabilities will be provided via the integration of emerging low-cost devices suitably scaled to the platform and mission requirements. Sensor/database registration error minimization will be provided for via the development of advanced software algorithms that recognize and determine errors and apply corrections.

In FY99, established concept definition specification and concluded simulation and mission analysis for ground-based GPS pseudolites. In FY00, concluded evaluation of GPS enhancement technologies and simulation of navigation system/database registration error minimization algorithm (TRL 4). By FY01, conclude demonstration/prototype of navigation system/database registration error minimization algorithm (TRL 5). By FY02, initiate technical demonstration of STO technologies with a major warfighter experiment (TRL 5). By FY03, conclude technical demonstration of STO technologies and transition technology (TRL 6). Products include Army GPS pseudolite concept, antijam GPS filters and antennas, navigation integration technology, and map/navigation registration error minimization algorithms.

Supports: PEO–Aviation, PEO–C^{3}S, PEO–IEW&S, PM–GPS.

TSO	TRADOC POC	STO Manager
Rob Saunders	Martin Bosemer	Paul M. Olson
SAAL–TT	DFD, Ft. Knox	CERDEC/C2SID
(703) 601–1546	(502) 624–2045	(732) 427–3912
329–1546	464–2045	987–3912

III.C4.1999.03—ADVANCED COMBAT IDENTIFICATION (CID) ARCHITECTURE. This STO advances the CID materiel capabilities by building upon the S&T-derived CID architecture. The objective is to develop and quantify the combat effectiveness improvements resulting from a comprehensive air-to-ground and ground-to-ground target identification (ID) and situational awareness utilization architecture, to provide both affordable and technically acceptable solutions to mission area needs.

In FY99, demonstrated through-the-sight display of integrated ID data from situational awareness and target ID sources in a virtual experiment, and demonstrated ID capabilities embedded in the Force XXI Land Warrior (FXXI LW) ensemble interoperable with the CID for Dismounted Soldier (CIDDS) system (TRL 5). In FY00, demonstrated integration of CIDDS functionality with Battlefield Identification System (BCIS) to provide vehicle-to-soldier ID capabilities, and demonstrated an automated SINCGARS-based ID capability for fire support teams. By FY01, demonstrate an integrated target ID and situational awareness capability for vehicle-to-vehicle ID, demonstrate a POC of ID capabilities for Apache Longbow, and evaluate the different counterintelligence architectures as a function of operational performance, cost, maturity, and interoperability (TRL 5/6).

Supports: PEO–IEW&S.

TSO	TRADOC POC	STO Manager
Rob Saunders	Chris Kearns	Gerardo J. Melendez
SAAL–TT	DBBL	SFAE–IEW–CI
(703) 601–1546	(706) 545–6391	(980) 987–5970
2329–1546	835–6391	987–5970

III.C4.2000.01—AGILE COMMANDER ATD. This STO develops and demonstrates C^2 applications for a functionally and physically agile, rapidly deployable, split-based headquarters (HQ) enabling commanders to execute distributed operations from the high-end spectrum of war to humanitarian assistance. The goals of the Agile Commander program include C^2 tools for very rapid development of COA, COA analysis (COAA), wargaming, and execution monitoring; and enterprise information and mobile adaptive computing capabilities enabling C^2 systems to conduct operations OTM by the commander and his staff. This program will focus on improving the combat capabilities of the heavy mechanized force, but will feature scalable products for all echelons.

During FY00, finalized selected technologies and architecture approach (TRL 3). By FY01, demonstrate initial semiautomatic COA/COAA tools (TRL 3/4). By FY02, demonstrate COA generation in half the

time and with three times the Blue and Red COAs, and demonstrate enterprise information applications (TRL 4/5). By FY03, mature DARPA command post of the future visualization/presentation technologies, demonstrate COAA and wargaming capabilities, demonstrate Web-based intelligent software agents for execution monitoring, demonstrate a scalable and reconfigurable C^4I multifunction operator environment with access to all TOC information, integrate Multifunctional On-the-Move Secure Adaptive Integrated Communications (MOSAIC) capabilities with Agile Commander software, and demonstrate technologies supporting connected and disconnected operations (TRL 5). By FY04, demonstrate intelligent software agents for execution monitoring of 300 events; and demonstrate, in a mobile prototype, integrated C^2 tools, enterprise information, and mobile adaptive computing capabilities for C^2 operations, both dispersed and OTM. A final demonstration, as part of a TRADOC limited objective experiment (LOE), will be conducted (TRL 5/6).

Supports: PEO–C^3S, Objective Force operations, PM–Army Tactical Command and Control System (PM–ATCCS), PM–FATDS.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	COL Michale Heredia	John Soos
SAAL–TT	BCBL(L)	CERDEC/C2SID
(703) 601–1546	(913) 684–8051	(732) 427–3723
329–1546	552–8051	987–3723

III.C4.2000.02—MULTIFUNCTIONAL ON-THE-MOVE SECURE ADAPTIVE INTEGRATED COMMUNICATIONS (MOSAIC) ATD. This program demonstrates mobile communications to support Battle Command Infrastructure Mobility. MOSAIC has three major focus areas: (1) bandwidth management—scaled bandwidth request based on precedence, support of bandwidth reservation, proxies to drive bandwidth aware applications, and the addressing of internet protocol (IP) quality of service (QoS) over tactical wireless links; (2) adaptive network protocols to support infrastructure mobility—ad hoc network protocols to support self-initializing, self-healing, adaptive, mobile networks while addressing security; (3) integration of commercial and DoD-developed wireless technologies—products from internal 6.2 efforts, DARPA products (i.e., Global Mobile (GloMo), airborne communications node (ACN)), and commercial products will be leveraged/integrated to demonstrate this mobile capability. These technologies are on the path to the mobile Objective Force, which is based on knowledge and speed.

In FY00, began integration of 6.2 efforts and DARPA GloMo protocols into a prototype short-range wireless system, and developed a security architecture (TRL 3). In FY01, integrate mobile protocols with the prototype medium-range wireless system and the ACN. In FY01/02, perform a laboratory experiment to demonstrate the seamless integration of the prototype communications systems and available networking protocols with integrated airborne and space communications (TRL 4). In FY02, evaluate the data collected during the laboratory experiment and, based on this data, enhance the communications and networking protocols to support increased mobility and seamless integration of the ACN and SATCOM. Develop protocols to scale bandwidth efficiently, support voice over IP, provide IP QoS, and provide information to bandwidth aware applications. Perform a field demonstration. In FY03, conduct a laboratory demonstration of the integration of the bandwidth adapting protocols, voice over IP, IP QoS, mobile networking protocols, ATM implementing switched virtual circuits, and the communications systems (TRL 5). In FY04, develop an integrated prototype system and demonstrate the objectives of this program as part of the Army Experimental Campaign Plan. Conduct a final demonstration of the integrated system with the ACN, space-based assets, and terrestrial systems (TRL 6).

Supports: FCS, PEO–C^3S, PM–Tactical Radio Communication System, PM–WIN-T, PM–Military Satellite Communications.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	Tom Mims	Gary Blohm
SAAL–TT	BCBL(G)	CERDEC/STCD
(703) 601–1546	(706) 791–2800	(732) 427–4277
329–1546	780–2800	987–4277

III.C4.2001.01—SMART SENSOR COMMUNICATION NETWORKS (SSCN). The focus of this program is to develop communications network solutions for forward-deployed, unmanned, clustered entities such as smart munitions, sensors, and robotic systems that will be deployed with the Objective Force and FCS and on the digitized battlefield of the future. Sensor technology enabling identification and tracking of enemy movements is critical to survival of a lightweight force. However, energy-efficient networked communications capabilities for miniature microsensors do not exist. These solutions will enable adaptive, self-healing, multihop communications networks with optimal routing algorithms that are secure and simultaneously exchange imagery and data traffic among the clustered entities and rearward to all echelons, including those beyond line of sight. Specific technological challenges include the development and adaptation of network protocols; low-cost, low-power radio technologies; high-efficiency, low-profile antennas; near-Earth propagation effect on antennas; beam resistance; and low probability of intercept/deception (LPI/LPD) and resolution of security issues associated with linking forward unmanned entities with the (secure) Tactical Internet.

By FY01, develop a common network architecture for unattended networks. demonstrate candidate radio protocols, and expand existing networking and communications to include duty cycle issues (TRL 4). By FY02, downselect the most promising commercial and emerging ARL radio prototypes; demonstrate protocols and components for low-power, and demonstrate miniature radios for acoustic/seismic sensors; develop prototype radio with integrated network protocols; and conduct evaluations in surrogate operational environment (TRL 5). By FY03, conduct initial demonstration of integrated acoustic/seismic sensor radio network in CER–01 Demonstration; determine system design changes (architecture, networks, protocols, etc.); and extend radio designs to include ECCM, security, and LPI/LPD (TRL 5). In FY04, enhance system integration of radios, protocols, security, and cosite mitigation (TRL 6). In FY05, demonstrate complete networked militarized sensor, munition, and robotic communications for the Objective Force and FCS. SUO, GloMo, and commercial technologies will be heavily leveraged to achieve solutions (TRL 6).

Supports: Sensors for Objective Force and FCS, Antipersonnel Landmine Alternative (APLA).

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos	COL Rodger Knox	John Gowens
SAAL–TR	BCBL(G)	ARL
(703) 601–1524	(706) 791–2057	(301) 394–1722
329-1524	780-2057	290–1722

III.C4.2001.02—ADVANCED ANTENNAS. This STO develops a family of highly efficient, practical, cost-effective antennas and subordinate products covering the 30-MHz to 44-GHz frequency range. Antennas will have higher gain and bandwidth to sustain robust, high-data-rate communications; greater agility for OTM operations; and lower profiles for reduced platform visual signatures. In addition, antennas will be capable of conformal integration within soldiers' clothing for improved mobility and survivability; and will be functional with the Joint Tactical Radio System (JTRS) multiband radio.

Products developed under this STO will include (1) multiband, multibeam phased-array antennas (PAAs) using thin-film ferroelectric and microelectromechanical systems (MEMS) technologies to enable tactical ground vehicles to simultaneously access multiple communication systems (multimission operations) from a single antenna (two-phase program initiated in FY02 (TRL 4)/FY04 (TRL 5) and demonstrated in FY04 (TRL 6)/FY06 (TRL 6)); (2) precision Attitude and Heading Reference Systems (AHRS) providing PAA guidance control for OTM communications at higher frequency bands and data rates (initiated in FY05 (TRL 5) and demonstrated in FY06 (TRL 6)); (3) body-borne and low-profile antennas for soldier (SOL) and vehicular (VEH) platforms to reduce unwanted platform interactions, to lower visual signatures, and to improve mobility (initiated in FY02 SOL (TRL 5)/FY05 VEH (TRL 4) and demonstrated in FY04 (TRL 6)/FY06 (TRL 5)); (4) optimized and computationally efficient modeling techniques to validate antenna design efforts and accurately predict FCS platform signal losses and range degradations (initiated in FY02 (TRL 3) and demonstrated in FY05 (TRL 5)); (5) reconfigurable-band switched antennas that can electronically change their radiating geometries and matching network topologies in response to a radio's control signal to achieve greater communication range and cosite interference reduction (two-phase program initiated in FY02 (TRL 4)/FY04 (TRL 4) and demonstrated in FY04 (TRL 6)/FY06 (TRL 6)); and (6) multiband antennas for ground and airborne applications to support the JTRS multiband, multimode radio (initiated in FY02 ground (TRL 5)/FY03 airborne (TRL 4) and demonstrated in FY03 (TRL 6)/FY06 (TRL 6)).

Supports: Objective Force, JTRS, CGS, MILSTAR, GBS, WIN–T.

TSO
Rob Saunders
SAAL–TT
(703) 601–1546
329–1546

TRADOC POC
COL Rodger Knox
BCBL(G)
(706) 791–2057
780–2057

STO Manager
Steven Goodall
CECOM/S&TCD
(732) 532–0445
992–0445

INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE AND ELECTRONIC WARFARE

III.IS.1996.01—MULTIMISSION/COMMON MODULAR UNMANNED AERIAL VEHICLE (UAV) SENSORS ATD. This STO demonstrates an affordable family of rapidly interchangeable EO/IR multispectral and lightweight moving target indicator (MTI) radar/synthetic aperture radar (SAR) payloads for future tactical or short-range UAVs. These common modular payloads will be form, fit, and interface compatible and share common electronics, datalink, and data compression. The radar payload will build upon successes in the current low-cost radar development program. The EO/IR payload will leverage results of the Aerial Scout Sensors Integration Program and use high-quantum-efficiency 3- to 5-μm staring arrays. The sensors will interface with the tactical common datalink and the tactical control station to deliver imagery intelligence products to Army users. These advanced sensor payloads will provide enhanced reconnaissance, surveillance, battle damage assessment (BDA), and target cueing for non-line-of-sight (NLOS) weapons.

In FY97, determined mission requirements and payload constraints. In FY98, determined commonality and modularity design approach, and initiated radar development. In FY99, initiated EO/IR development, radar fabrication/assembly, and sensor subsystem testing. In FY00, completed subsystem test and initiated integration and flight tests (TRL 5). By FY01, complete performance testing, participate in operational demonstrations and AWEs (TRL 7), and prepare for transitioning to SSD in FY02.

Supports: Tactical UAV, UAV JPO.

TSO	TRADOC POC	STO Manager
Rob Saunders	Bob Bolling	Dorothy Bartling
SAAL–TT	U.S. Army TRADOC BCBL	CERDEC/I2WD
(703) 601–1546	(602) 538–7500	(732) 427–2895
329–1546	879–7500	987–2895

III.IS.1999.01—QUICK LOOK. The focus of this STO is to demonstrate an airborne sensor platform (mini UAV), fired from a 155-mm howitzer, that will provide the field artillery brigade commander real-time BDA and target sensing. The Quick Look vehicle will fly out to a maximum range of 50 km to acquire and transmit targeting information (i.e., video, GPS) back to the delivery platform via a wireless sensor-to-shooter link.

In FY99, completed a performance specification, initiated baseline designs, and conducted component fabrication and subsystem testing of critical components. In FY00, refined concept design and began system fabrication and integration. By FY01, begin system testing. By FY02, conduct a demonstration showing the system's ability to provide the user with target information on stationary and moving military vehicles at ranges up to 50 km.

Supports: Supports: Crusader, Paladin, PGMM.

TSO	TRADOC POC	STO Manager
John Appel	MAJ Chapman	Robert Werko
SAAL–TT	D&SABL	ARDEC
(703) 601–1537	(580) 442–6632	(973) 724–5854
329–1537	639–6632	880–5854

III.IS.1999.02—JOINT INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE (JISR) ACTD. This STO provides a new capability for the brigade commander: distributed, nonlinear battlefield operations, and an independent mode of brigade intelligence operations. For the first time, the brigade commander will be able to draw down, in real time, intelligence data from a combination of national and tactical assets and get an integrated Blue and Red forces picture. JISR will provide the necessary communications, networking, and software and sensor integration efforts to enable the brigade commander to understand the enemy operations on an expanded battlespace.

In FY99–00, developed mission planning and analysis tools, performed collection management, and completed database efforts. In FY01–02, develop data correlation and queuing, complete mission planning, and develop analysis tools. In FY03, complete prototyping, systems integration, and data control to units; and conduct final full capability demonstration (TRL 7).

Supports: Objective Force, PEO–IEW&S.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	Michael Powell	LTC Mark Baehr
SAAL–TT	BCBL(H)	JPSD
(703) 601–1546	(520) 538–3841	(703) 704–1861
329–1546	879–3841	654–1861

III.IS.2000.01—WARFIGHTER ELECTRONIC COLLECTION AND MAPPING. This STO provides the warfighter with an organic capability to put at risk every enemy tactical RF emitter on the battlefield. Embedded RF emitter collection and mapping technology in multifunction devices, coupled with sensor feeds, offers near-real-time emitter detection, location, and identification. An upgrade to legacy radios will provide a collection function. Leap-ahead signal processing, conformal low-visual-observable antennas, and templating technology provide exploitation of communications intelligence (COMINT), electronic intelligence (ELINT), and measurement and signature intelligence (MASINT) at the maneuver unit level without additional hardware. A new set of signal processing and visualization tools will be designed, enabling a reduction in linguists and scarce signal analysts to be reassigned. The software will be platform independent algorithms with the potential for HTI. Unit-level RF sensors will detect existing emitters as well as the new threat of modern low-power emitters in the local area. This STO leverages several DARPA programs and enables the Army to "own the spectrum" much like it "owns the night." It provides commanders of forwardly deployed elements a new capability to "see" over/through terrain masking with current RF kit, locate the enemy, and provide real-time threat warnings in the area of interest.

In FY00, developed electronic mapping object models; completed technology development for advanced antennas and MEMS low-voltage switching, and provided initial input to battle lab DIS to assess collection, timing allocation, and operational concept of multifunction capability. By FY01, develop electronic mapping signals intelligence (SIGINT) Object Model and advanced algorithms using DSP-based optimization techniques, AI cueing algorithms, and prototype development of multifunction RF collector; continue battle lab DIS experiments to further refine operational concept and develop signal mapping visualization and analysis tools (goal 15 minutes), including updates with removal of stale data. By FY02, develop advanced wavelet-based algorithms for specific emitter identification (SEI); demonstrated multifunction electronic collection and mapping system simulation; demonstrate fully

distributed electronic mapping using a combination of field experiments and DIS experiments; and demonstrate operational workstation (TRL 5). By FY03, demonstrate Warfighter RF Collection System coresident on surrogate RF radio platform; and demonstrate linking of processing and dissemination to joint intelligence, surveillance, and reconnaissance and methods of visualization of the collected data to all levels of intended users (goal <2 minutes) (TRL 6).

Supports: PEO–IEW&S, Objective Force.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	Michael Powell	Cal Eanes
SAAL–TT	BCBL(H)	CERDEC/I2WD
(703) 601–1546	(520) 538–3841	(732) 427–7043
329–1546	879–3841	987–7043

III.IS.2001.01—MULTIMISSION RADAR (MMR). This STO develops a HMMWV/FCS-configured sensor for RSTA, situational awareness, alerting and cueing, and fire control quality information for air and missile defense (AMD) engagements. MMR will enable the Army to rapidly deploy a single sensor that will perform multiple missions (e.g., AMD engagements of rockets, artillery, mortars, UAVs, cruise missiles, and both rotary- and fixed-wing aircraft; counter fire target acquisition that enables precision attack munitions (PAM) while simultaneously providing data to intelligence, maneuver, ATC, etc.). MMR will be small and light enough for insertion via single CH–47 or C–130 sortie, but will still have long-range target acquisition capabilities.

By the end of FY01, complete SOCOM "MMR Lite" radar development, deliver this system to SOCOM, transition the technology to MMR, and complete MMR procurement package (TRL6). By FY02, award the MMR contract, conduct the preliminary design review, and develop the simulation plan. By FY03, complete the system design, conduct the CDR, and complete the test and demonstration plans. By FY04, develop software and algorithms for target classification, mission sorting, and target queue management; conduct hardware and software integration test; and start engineering test (TRL 5), By FY05, complete development of MMR hardware and software, and perform engineering test (TRL 6). By FY06, conduct user demonstration and transition. The effort will culminate in demonstrations of a fully tested MMR system and prime item development specifications suitable for moving into an SDD phase (TRL 6/7).

Supports: Objective Force, PEO–AMD, PM–SHORAD, PM–ATC, SOCOM, PM–Firefinder.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	MAJ Rothlein	Paul Yao
SAAL–TT	DSABL	CERDEC/I2WD
(703) 601–1546	(580) 442–6528	(732) 427–6524
329–1546	639–6528	987–6524

III.IS.2001.02—SENSORS FOR THE OBJECTIVE FORCE. This program develops and integrates offboard sensor packages onto mobile platforms (unattended ground vehicles (UGVs), mini UAVs, unattended ground sensors (UGSs)) and create a system-of-systems that can be networked in complex terrain (including MOUT). Sensor networking and data fusion provides faster targeting and target ID with reduced false alarms, provides the commander near-real-time situational awareness for direct- and indirect-fire weapons and threat avoidance, and enables remote monitoring of areas out to ~10 km. The program integrates and demonstrates enabling sensors—uncooled IR, flash laser with SWIR, mini UAV, UGV, microsensors (acoustic, seismic, IR imaging, magnetic, and RF); assesses network communication performance resulting from the Warrior Extended Battlespace Sensors STO and Smart Sensor Communications Network STO; and includes an intelligence reachback capability for threat profile development, sensor deployment, and smart data management. Included are MITL virtual and live experiments with MMBL and DBBL in warfighter operational environments to address hardware and operational integration issues, establish solutions, investigate new operational concepts/tactics, techniques, and procedures (TTPs), and validate component and system TRLs.

By FY02, establish user integrated product team (IPT), finalize operational architecture, and conduct simulations and field experiments to make system design tradeoffs (TRL 4). By FY03, integrate sensor prototypes, networked communications, and sensor data management. Demonstrate capability of NLOS situational awareness/target acquisition (TRL 5). By FY04, refine prototype sensor packages, integrate C^2 station into FCS surrogate, and conduct operational experiments. Improve data fusion/aided target recognition algorithms and optimize the situational awareness display (TRL 6). By FY05, demonstrate unmanned platform applications along with data management and system changes. Finalize specifications for transition to SDD (TRL 6).

Supports: FCS, Objective Force Soldier Systems.

TSO	TRADOC POC	STO Manager
Rob Saunders	COL Henry Hughes	Michael Jennings
SAAL–TT	DFD, USAARMC	CERDEC/NV
(703) 601–1546	(502) 624–5050	(703) 704–1032
329–1546	464–5050	654–1032

GROUND COMBAT AND TACTICAL SYSTEMS

III.GC.1996.01—GROUND PROPULSION AND MOBILITY. Ground vehicle mobility advances for the combat and tactical vehicle fleets will be achieved through cooperative agency electric drive research and high-performance ground vehicle running gear technology developments. Running gear advances will apply sensors, intelligence, and new material technologies to tracked- and wheeled-vehicle suspension systems. These mobility advances will enhance system survivability and operational effectiveness through smaller and lighter systems with improved ride and agility, reduced acoustic and IR signatures, and quiet slope operations for reconnaissance/scout-type missions.

In FY98, demonstrated high-power metal oxide semiconductor (MOS) thyristers, and completed operational effectiveness simulation payoff predictions. In FY99, completed band track and wheeled vehicle suspension demonstrations. In FY00, selected energy storage concepts (TRL 6). By FY01, demonstrate MOS-controlled thyristers in a vehicle and complete performance testing. ARL will fabricate gate turn-off thyristors and develop the associated gate drive and motor circuits that will run a 2-hp, three-phase induction motor from a 600-Vdc bus using PCM at 2 kHz. By FY02, the thyristors will be able to handle at least 200 A/cm^2 and operate while being cooled by engine oil, which is typically at a temperature of 200°C. Also in FY01, demonstrate the operational effectiveness and survivability enhancements of semi-active (adaptive) suspension and band track technologies on a vehicle demonstrator. An integration effort will result in a Ground Propulsion Mobility Demonstrator, which will be electrically driven and capable of meeting the power demands of an EM gun and other all-electric vehicle requirements. The Army and DARPA will jointly demonstrate an electric drive combat vehicle (TRL 6).

Supports: FCS, tactical wheeled vehicle.

TSO	TRADOC POC	STO Manager
John Appel	Charles Campbell	Dan Herrera
SAAL–TT	MBSBL	TARDEC
(703) 601–1537	(502) 624–1963	(810) 574–6411
329–1537	464–1963	786–6411

III.GC.1997.01—FUTURE SCOUT AND CAVALRY SYSTEM (FSCS) ATD. This program demonstrates the operational potential of a lightweight scout vehicle integrating scout-specific technologies with complementary advanced vehicle technologies. This effort is a cooperative program with the United Kingdom. Using the Bradley M3A3 as a baseline, the FSCS ATD will increase vehicle and crew survivability by 20 percent, increase target detection rate by 600 percent, increase target recognition range by 35 percent, increase mobility by 15 percent, increase crew efficiency by 25 percent, reduce vehicle silhouette by 30 percent, and achieve transportability of one FSCS in a C-130 and three FSCSs on a C-17 aircraft.

In FY98, designed and built advanced crew station(s) and performed a concept analysis. In FY99, initiated a vehicle-level systems integration laboratory. In FY00, developed detailed design and initiated subsystem fabrication (by contractors) and conducted Analysis of Alternatives and Affordability Analysis (government). By FY01, complete subsystem fabrication, perform demonstrator fabrication and integration, and present contractor costs at a three-star affordability review to assess contractor costs and the Analysis of Alternatives. By FY02, complete user experiments, validate improved battlefield performance, and conduct operational evaluation to assist in tactics, techniques; and procedure devel-

opment (TRL 6). This integration effort leverages technologies developed in the following STOs: Ground Propulsion and Mobility, Target Acquisition ATD, Multifunctional Sensor Suite ATD, Hunter Sensor Suite ATD, Combined Arms Command and Control ATD, Digital Battlefield Communications ATD, Hit Avoidance ATD, Crewman's Associate ATD, Intra-Vehicle Electronics Suite TD, and Composite Armored Vehicle ATDs.

Supports: FCS, IAV.

TSO	TRADOC POC	STO Manager
John Appel	COL Henry J. Hughes III	Roland A. Asoklis
SAAL–TT	USAARMC	PM FSCS
(703) 601-1537	(502) 624-5050	(810) 574-7700
329–1537	464–5050	786–7700

III.GC.1997.02—MULTIFUNCTION STARING SENSOR SUITE (MFS^3) ATD. This program demonstrates a modular, reconfigurable MFS^3 using sensor fusion and multiple advanced sensor components, including staring IR arrays, multifunction laser, and acoustic arrays. The MFS^3 will provide ground vehicles, amphibious assault vehicles, and surface ships with a compact, affordable sensor suite for long-range, noncooperative target ID, low-signature target acquisition, mortar/sniper fire location, and air defense targeting against low-signature UAVs and long-range helicopters.

In FY98, completed sensor modeling and initiated system simulation; conducted an early demonstration and data collection of long-range ID using a mid-wavelength IR (MWIR) sensor with ultra-narrow FOV. In FY99, completed sensor component simulation and risk reduction; developed sensor backplane that fully integrates aperture, power, and signal processing requirements for multiple platform applications; completed design of medium-format staring sensor capable of being reconfigured for 3- to 5-μm or 8- to 12-μm operation. In FY00, conducted early user demonstration of three FOV staring FLIRs; and integrated staring FLIR, multifunction laser, and acoustic cueing components and processing with common backplane. By FY01, complete MFS^3 vehicle integration; demonstrate the capability for automated surface-to-surface, surface-to-air, and air-to-ground search, acquisition, and noncooperative ID (TRL 5). By FY03; integrate weapon/fire location processing; and demonstrate capability to detect and accurately locate hostile mortar/sniper fire (TRL 6).

Supports: PEO–GCSS, PM–FCS.

TSO	TRADOC POC	STO Manager
Rob Saunders	Chris Kearns	Paul Laster
SAAL–TT	DBBL	CERDEC/NVESD
(703) 601–1546	(706) 545–6391	(703) 704–3492
329–1546	835–6391	654–3492

III.GC.1999.01—FULL-SPECTRUM ACTIVE PROTECTION (FSAP). The objective of this STO is to demonstrate a single universal countermeasure for protection of ground combat vehicles against smart top-attack, hit-to-kill ATGMs and tube-launched KE and HEAT threats. FSAP component technology will be at TRL 5 by FY05, A FSAP system design for vehicle integration will be delivered in FY05. This joint program among TARDEC, ARDEC, and ARL will exploit new countermeasures and adapt and develop technologies from other programs. The FSAP approach will be balanced in consonance with advanced armor technology, including development of armor systems to capture residual debris, and it will consolidate AP technology demonstrators. The FSAP will be integrated into the enhanced commander's decision aid (CDA) for optimal utility.

In FY99, identified and assessed applicable countermeasures. In FY00, demonstrated CMs capable of defeating large-caliber KE and HEAT, and assessed viable countermeasure-dispensing subsystem components. By FY01, adapt models and conduct simulations to determine viable system candidates. By FY02, complete optimal individual sensor, launcher, delivery, armor, and countermeasure evaluations. By FY03, design and assess the FSAP baseline system By FY05, complete final system demonstration and design (TRL 5).

Supports: FCS, Crusader, legacy systems.

TSO	TRADOC POC	STO Manager
John Appel	COL Joseph O. Rodriguez	Jim Soltesz
SAAL–TT	Headquarters, TRADOC	TARDEC
(703) 601–1537	(757) 788-2217	(810) 574–5653
329–1537	680-2217	786–5653

III.GC.1999.02—CREW INTEGRATION AND AUTOMATION TESTBED (CAT) ATD. This program demonstrates the crew interfaces, automation, and integration technologies required to operate and support FCS. This ATD will consist of two identical advanced technology crew stations, along with a safety driver crew station, integrated into a C-130 transportable surrogate testbed vehicle. The CAT ATD will leverage research investments from the Rotorcraft Pilot's Associate and Crewman's Associate ATDs. Alternative positions of crew stations will be evaluated using both front-to-back and side-by-side positioning. The goals are to demonstrate a more efficient use of manpower for three key battlefield tasks: 100 percent of fight (19K), scout (19D), and carrier (11M) crew tasks; a 10X increase in architecture performance; and a 250,000 SLOC increase in software reuse. Specific technologies to be integrated include helmet-mounted displays (HMDs), head trackers, panoramic displays, intelligent driving decision aids, semiautonomous driving technology suite, automated route planning, object-oriented software backplane, and a combat vehicle graphics map toolkit. MANPRINT issues will be addressed through human factors modeling and analysis early on and through soldier and system performance measurement during experimentation.

In FY00, completed technology suite system engineering and design. By FY01, develop baseline semi-autonomous driving and route planning (TRL 3). By FY02, adapt and develop mission planning and rehearsal technologies and cognitive decisions aids. By FY03, adapt and implement embedded training and complete development of driving technologies and decision aids, and demonstrate technologies on vehicle testbed (TRL 5). By FY04, develop embedded battlefield visualization, integrate HMDs and panoramic displays, demonstrate vehicle testbed, and perform Battle Lab Warfighter Experiment (TRL 6).

Supports: FCS, Open Systems JTF, Joint Technical Architecture- Army, WSTAWG.

TSO	TRADOC POC	STO Manager
John Appel	Martin Bosemer	Bruce Brendle
SAAL–TT	Armor Center & School	TARDEC
(703) 601–1537	(502) 624–2045	(810) 574–5798
329–1537	464–2045	786–5798

III.GC.2000.03—FUTURE COMBAT SYSTEMS (FCS). The Army needs lightweight, overwhelmingly lethal, yet strategically deployable, self-sustaining, survivable combat systems for the 2010–2020 timeframe. As a joint DARPA / Army program, FCS will use a combination of industry and government studies, investigations, and conceptual design efforts to develop concepts that will demonstrate desired capabilities as well as mature requisite technologies that will provide advanced-technology suites to meet the Army's needs. FCS will be a multifunctional, multimission, reconfigurable system-of-systems designed to maximize joint interoperability, strategic transportability, and commonality of mission roles, including direct and indirect fire, air defense, reconnaissance, troop transport, countermobility, nonlethal fire and C^2 on the move. FCS will provide revolutionary lethality through incorporation of advanced direct, indirect, and air defense modules; and advanced mobility by integrated advanced propulsion technologies such as electric drive / suspension, hybrid electric power, or fuel cells / reformers. FCS will reduce up to 90 percent of logistic / sustainment demands by effectively combining technologies to reduce platform size, weight, fuel consumption, and manning requirements; increase commonality; increase onboard training and battle rehearsal capability embedded in vehicle electronics; and provide revolutionary survivability using a combination of innovative lightweight armors, Active Protection Systems, signature management, and vehicle structure.

In FY00, selected multiple contractor teams through competitive process to begin developing FCS concept alternatives, and initiated DARPA / Army enabling technology programs. By FY01, continue concept development, establish integrated data environment, and initiate concept refinement by M&S. By FY02, recompete contracts and select most promising concept alternatives; mature competing concept alternatives; and demonstrate enabling technologies to achieve TRL 5 by the FY03 technology readiness review (TRR). By FY03, finalize FCS organizational, operational, and materiel concepts; obtain program continuation decision from Chief of Staff; initiate system-of-systems prototype development and selected multiple-variant demonstrations; complete all technology demonstrations at TRL 5; and transition enabling technologies to the FCS demonstration program. By FY05, fabricate and test multiple FCS platform variants, and demonstrate and validate FCS prototype by leveraging modeling and simulation. By FY06, transition to SDD—Milestone B.

Supports: FCS.

TSO	TRADOC POC	STO Manager
John Appel	COL Joseph O. Rodriguez, Jr.	LTC Marion Van Fosson
SAAL–TT	HQ TRADOC	DARPA
(703) 601–1537	(757) 788–2217	((703) 646–7499
329–1537	680–2217	426–7499

III.GC.2000.04—ROBOTIC FOLLOWER ATD. This STO develops, integrates, and demonstrates the set of technologies required to achieve unmanned follower capabilities for future land combat vehicles (e.g., FCS). These technologies will support a wide variety of FCS/Objective Force applications such as Rucksack Carrier, Supply Platoon, NLOS/BLOS Fire, and Rear Security. A key tenet for the robustness and speed of the follower systems is the ability of the manned leader to provide a high-level proofing of the follower's path, avoiding areas that would impede or confuse the unmanned followers, which operate with minimal user intervention. This STO employs a series of demonstrations that will successively increase the follower performance and improve the maturity of the software algorithms, SMI, and sensor technology for transition to the FCS program. In FY01, the follower technology will be baselined on the Demo III XUV. To meet the April 2003 TRL 5 requirement, the program will use the the Demo III XUV chassis, which have sufficient mobility to meet the interim exit criteria and demonstrate follower capabilities to FCS contractors. For the April 2004 TRL 6 requirement, the technology will be ported to a more mobile chassis that is capable of meeting the full exit criteria.

In FY01, perform concept analysis to identify technology approaches for primary and backup modalities; define system requirements for both lead and follower vehicles; define baseline system architecture; and demonstrate multiple-vehicle following at up to 20 mph over a TRADOC-defined cross-country terrain (TRL 3). The vehicles will follow electronic navigation "breadcrumbs" from a lead vehicle and perform obstacle detection and avoidance. By FY02, integrate leader technology (navigation, communication, software maturity index) in a HMMWV; continue algorithm development to increase speed, reliability, and temporal/spatial separation of the following vehicles; and pursue backup mode to GPS "breadcrumbs" technology. By FY03, demonstrate through modeling the capability of scaling the technology to FCS; obtain a more mobile off-the-shelf chassis; implement system architecture and drive-by-wire capability; procure long-lead sensors and components; and demonstrate technology components at TRL 5 on SUVs to achieve up to 35 mph (chassis limited) on-road following and up to 20 mph cross-country following with vehicle separation of up to 12 hours or 160 km. By FY04, demonstrate technology components at TRL 6 to achieve up to 50 mph on-road following and up to 30 mph cross-country following with separation of up to 24 hours or 750 km. By FY05, collaborate with PM-FCS to transition follower technology into the FCS architecture, conduct safety certification, integrate mission equipment package, and perform operational testing.

Supports: FCS, joint service UGV programs.

TSO	TRADOC POC	STO Manager
John Appel	COL Joseph O. Rodriguez, Jr.	Bruce Brendle
SAAL–TT	HQ, TRADOC	TARDEC
(703) 601–1537	(757) 788-2217	(810) 574-5798
329–1537	680–2217	786-5798

III.GC.2001.01—SIGNATURE MANAGEMENT FOR FUTURE COMBAT SYSTEMS. This STO assesses and tests advanced signature hardware technologies that will reduce the high costs of today's technologies. This project will improve existing modeling tools to characterize advanced hardware performance and provide inputs for FCS virtual prototyping. Technical approaches from TARDEC, ARL, and contractors will be characterized to improve model inputs, increase accuracy, and validate performance. Field testing will measure performance, burdens, and user acceptance of specific technologies. Currently achievable technology base hardware capability is a 50 percent signature reduction at a TRL of 4 (tech demo). For transition into FCS SDD by FY05, a minimum acceptable capability is a 70 percent signature reduction

at a TRL of 6. The technical goal is demonstration of 80 percent signature reduction in a validated virtual vehicle concept. Model improvements, technologies investigated, and results will directly transition to the FCS contractors and support FCS milestone decisions on technical requirements and affordability from FY01 to FY05.

By FY01, complete a low-observable (LO) requirements analysis for FCS. By FY02, conduct material- and system-level tests to improve model inputs (TRL 5). By FY03, provide virtual prototypes, MMBL computer-aided virtual environment (CAVE) analysis, and hardware test results to support the FCS CSA review (TRL 5). By FY04, complete additional hardware testing and CAVE evaluation to validate FCS modeling results and analysis inputs (TRL 6). By FY05, conduct the final system evaluations and test validation to support the FCS SDD and Milestone B review (TRL 6).

Supports: FCS.

TSO	**TRADOC POC**	**STO Manager**
John Appel	COL Henry J. Hughes III	David Thomas
SAAL–TT	USAARMC	TARDEC
(703) 601–1537	(502) 624–5050	(810) 574–8911
329–1537	464–5050	786–8911

III.GC.2001.02—SURVIVABILITY TECHNOLOGY INTEGRATION PROGRAM. This program integrates and demonstrates a suite of advanced survivability technologies for protection of ground combat vehicles against multiple threats and munitions. Survivability technologies that are integrated and demonstrated under this STO include APSs, advanced armors, electronic sensors, and countermeasures. Active protection efforts will be focused on demonstrating threat sensors and tracking software algorithms, and hard-kill countermeasures needed for an APS. The end result will be the demonstration of a baseline APS for the Army that will be effective against chemical energy (CE) munitions (e.g., shaped-charge warheads) and top-attack munitions. At the conclusion of this STO in FY02, the baseline TRL 06 APS components will be transitioned to the Full-Spectrum Active Protection System for inclusion of large-caliber, gun tube-fired CE and KE (i.e., long rod) defeat capability. Under this STO, electronic sensors and countermeasures will be demonstrated against the class of threat for which "soft kill" is more effective. Advanced armor will be tested against small and medium KE threats and the residual debris from threats engaged by APS "hard kill" countermeasures will be characterized. APS and electronic countermeasures have potential for providing enhanced protection of all combat vehicles and are an attractive solution to reduce the weight burden of passive armor for lightweight vehicle platform classes such as the FCS program.

In FY00, completed detailed design of the survivability suite and component fabrication (TRL 4). In FY01, complete component and subsystem testing and integrate the complete survivability system on a ground combat vehicle testbed (TRL 5). In FY02, complete field testing of the integrated survivability suite against live threats (TRL 6).

Supports: FCS, recapitalization.

TSO	**TRADOC POC**	**STO Manager**
John Appel	Col Hughes/COL Stone	Steven Schehr
SAAL–TT	USAARMC/USAIC	TARDEC
(703) 697–1537	(502) 624–5050/(706) 545–1515	(810) 575–8972
329–1537	464–5050/385–1515	786–8972

WEAPONS

III.WP.1994.01—PRECISION-GUIDED MORTAR MUNITION (PGMM) ATD. This STO demonstrates a capability to defeat a point target in a laser-designated mode at a range of 12 km with a 120-mm mortar munition; and demonstrate the viability of a GPS/Inertial Navigation System (INS) sensor/seeker guidance package incorporated into the PGMM to achieve accuracy requirements.

In FY98, conducted a seeker captive flight test. In FY00, conducted an extended-range firing test to verify 12-km range capability; investigated GPS/INS technologies for improved performance at extended range and in MOUT; and developed an integrated GPS/INS PGMM and conducted a MOUT operational experiment. In FY00–01, perform a comprehensive HITL test and simulations to validate hardware performance (TRL 6).

Supports: DMBL, MOUT ACTD, FCS.

TSO	**TRADOC POC**	**STO Manager**
John Appel	LTC Doug Litavec	Matt Cilli
SAAL–TT	US Army Infantry Center	ARDEC
(703) 601–1537	(706) 545–1016	(973) 724–6655
329–1537	835–1016	880–6655

III.WP.1996.01—DIRECT-FIRE LETHALITY (DFL) ATD. This STO focuses on enhancing the hit-to-kill capability of the Abrams Tank against explosive reactive armor (ERA) protected threats under both stationary and moving firing conditions.

In FY99, completed design and initiated fabrication of the gun elevation drive and the optical fiber muzzle reference sensor. In FY00, demonstrated novel penetrator lethality up to 70 percent greater than the M829A2 (TRL 5/6). By FY01, demonstrate radial thruster capability to correct for multiple jump errors in achieving 30–70 percent increase in system accuracy (TRL 5). Also in FY01, demonstrate an integrated 120-mm KE cartridge to defeat the 2005 ERA protected threat with up to 70 percent increase in lethality over the M829A2, and 30–70 percent increase in system accuracy under stationary conditions over the M829A2/M1A2 (TRL 7). [*Note:* The Advanced KE Cartridge Program is a joint effort with PM—Tank Medium-Caliber Armament System (PM–TMAS). The PM provided $3.0 million in FY99 and is providing $2.0 million in FY00 and FY01 to support novel penetrator development.]

Supports: FCS, 120-mm KE tank munitions, M1A2 SEP.

TSO	**TRADOC POC**	**STO Manager**
John Appel	A. Winkenhofer	Anthony Sebasto
SAAL–TT	USAARMC	ARDEC
(703) 601–1537	(502) 624–8064	(973) 724–7004
329–1537	464–8064	880–7004

III.WP.1996.02—OBJECTIVE CREW-SERVED WEAPON (OCSW) ATD. This STO develops and demonstrates a lightweight, truly two-man-portable, crew-served weapon system providing the dismounted soldier with overwhelming lethality resulting in increased survivability through long-range (out to 2,000 m) defeat of protected personnel targets in defilade. The principal objective is to demonstrate armor-piercing warhead potential to defeat lightly armored vehicles, watercraft, and slow-moving aircraft out to 2,000 m.

In FY99, demonstrated threshold active protection warhead light armor penetration of 2-inch (51 mm) rolled homogeneous armor with the goal of penetrating (51 mm) high-hardness armor out to 2,000 m. In FY00, demonstrated from a lightweight (<50 pounds) weapon (gun, pintle, transversing and elevating mechanism, and tripod) fully integrated fuze functions of airburst, point detonation, and self-destruct; and rapid-fire (burst mode) fuze set of high-explosive precision airburst munition (TRL 4). By FY01, demonstrate gun-launched airburst using integrated crew-served fire control (leveraged from OICW ATD STO) (TRL 5). By FY02, conduct safety and technical tests, user training through virtual simulations, and an early operational assessment through a DBBL experiment. Demonstrate operational utility and technological maturity (and achievement of exit criteria) (TRL 5/6).

Supports: FCS, Objective Force

TSO	TRADOC POC	STO Manager
John Appel	COL Stone	Vern Shisler
SAAL–TT	USAIC	ARDEC/JSSAP
(703) 601–1537	(706 545–1515	(973) 724–6009
329–1537	835–1515	880–6009

III.WP.1998.01—LINE-OF-SIGHT ANTITANK (LOSAT) ACTD. This program demonstrates increased lethality against current and future threat armor and APSs and hardened high-value targets, including bunkers and reinforced urban structures. The ACTD will assess survivability of the HMMWV-based system and develop a concept of operations for survivability through deception. The ACTD will also demonstrate enhanced deployability/mobility with the ability to fire upon landing. LOSAT operates as a kinetic kill mechanism and will demonstrate operation in day/night and adverse weather conditions.

In FY98, provided simulation analysis activities to support developmental requirements. By FY02, provide system test results and participate in BLWE that will demonstrate deployability, survivability, and lethality (TRL 6). By FY03, hardware residuals will include as deliverables 13 fire units and 178 missiles (TRL 7).

Supports: PEO–Tactical Missiles, PM–KEM.

TSO	TRADOC POC	STO Manager
Bruce Zimmerman	COL Mitchel Poodry	Rich Paladino
SAAL–TT	DBBL	AMRDEC
(703) 601–1559	(706) 545–2310	(256) 842–0851
329–1559	835–2310	788–0851

III.WP.1998.02—TANK EXTENDED-RANGE MUNITION (TERM). This STO demonstrates precision munition technology and associated fire control, including target handoff from a remote sensor to defeat targets at ranges in excess of 8 km. The munition will defeat point targets at extended ranges (up to 3X range increase over M829A2). TERM will expand the tank battlespace by engaging high-value targets in both LOS and NLOS modes.

In FY98, completed a technical description and initiated baseline designs. In FY99, finalized design, initiated and tested component hardware fabrication, and reviewed control error budget methodology. In FY00, sensor demonstrations were conducted (tower and captive flight tests) to demonstrate critical sensor features. The concept design was refined, and the fire control system definition/design methodology was initiated. By FY01, demonstrate the candidate technologies to reduce risk in their concepts, including warhead, propulsion, and airframe demonstrations. In FY02, transition sensor technologies to III.WP.1999.01, Multirole Armament and Ammunition ATD.

Supports: FCS, Abrams.

TSO	TRADOC POC	STO Manager
John Appel	A. Winkenhofer	Mark Nicolich
SAAL–TT	USAARMC	ARDEC
(703) 601–1537	(502) 624–8064	(973) 724–6717
329–1537	464–8064	880–6717

III.WP.1999.01—MULTIROLE ARMAMENT AND AMMUNITION ATD. The STO objective is to develop and demonstrate a lightweight, multimission armament system and munition suite for the FCS. This effort will incorporate force-level trade studies, mission requirements analysis, and demonstrations of major component technologies.

By FY01, complete review of mission requirements, design of cannon, autoloader, fire control, ETC propulsion and turreted armament system, advanced KE design and initial Multipurpose Extended-Range Munition (MP–ERM) and Smart Cargo designs; warhead development of a compact shaped-charge and GEN II/collinear explosively formed penetrator (EFP). By FY02, complete manufacturing of lightweight cannon, autoloader, fire control, ETC propulsion, and turreted armament system; conduct limited gun testing of KE composite sabot; and complete Smart Cargo and MP–ERM projectile design and laboratory demonstrations of shaped-charge and EFP warheads (TRL 5). By FY03, conduct system component critical demonstrations; complete system integration laboratory (SIL) demonstration of fire control functionality; complete functional demonstrations of launcher/autoloader concepts and turret manufacturing/integration; demonstrate composite sabot with integration of novel penetrator; conduct MP–ERM armor and high-g tests; conduct Smart Cargo component high-g tests; and initiate optimization of shaped-charge and EFP warheads in prototype FCS designs (TRL 5). By FY04, conduct full-up integrated turret system (turret slew, gun elevation, and autoloader feed rate) and firing demonstration of ETC propulsion for KE projectile; demonstrate KE projectile flight and armor defeat vs. 4-km target; conduct MP–ERM seeker high-g tests and guide-to-hit demonstration; complete Smart Cargo component high-g testing; complete optimization of shaped-charge and EFP warheads; and demonstrate high-energy, less-sensitive explosive (TRL 6). By FY07, demonstrate Smart Cargo round (TRL 7).

Supports: FCS, USAARMC, USAFAS, USAIS, CASCOM, joint services.

TSO	TRADOC POC	STO Manager
John Appel	COL Joseph O. Rodriguez	Mark Ford
SAAL–TT	Headquarters, TRADOC	ARDEC
(703) 601–1537	(757) 788–2217	(201) 724–3425
329–1537	680–2217	880–3425

III.WP.2000.01—OBJECTIVE INDIVIDUAL COMBAT WEAPON (OICW) SYSTEM ENHANCEMENTS. This STO will rapidly develop, demonstrate, and transition lethality enhancing and weight/cost reducing technologies into the OICW system platform to ensure LW battlefield superiority.

In FY00, designed and built prototype MEMS safe and arming devices, and demonstrated function in a laboratory environment. By FY01, demonstrate a gun-launched MEMS-based safe and arming mechanism and microenergetic initiation to permit a 75 percent volume/50 percent cost reduction in the fuze safe and arming; and establish alternative warhead designs incorporating directed air burst technology for increased lethality and potential weight reduction. By FY03, demonstrate probability of incapacitation greater than 50 percent at 500 m with new munition design; and demonstrate a ruggedized, multi-axis laser steering and target tracking capability that provides a 100 percent increase in detecting available targets and a 50 percent increase in probability of correct laser against targets going to ground at 500 m (TRL 4/5).

Supports: OICW, OCSW.

TSO	TRADOC POC	STO Manager
John Appel	COL Frank Stone	Matthew Zimmerman
SAAL–TT	USAIC	ARDEC
(703) 601–1537	(706) 545–1515	(973) 724–7993
329–1537	835–1515	380–7993

III.WP.2000.02—COUNTERACTIVE PROTECTION SYSTEMS (CAPS) THIRD-GENERATION RADIO FREQUENCY COUNTERMEASURES (RFCM). This STO will demonstrate, in missile flight tests, countermeasures that can defeat current and future threat Active Protection Systems (APS) in 95 percent of engagements.

By the end of FY01, demonstrate a brassboard CAPS device that defeats future APS radars at nominal engagement conditions. By the end of FY02, demonstrate a missile model equipped with a flight prototype CAPS device that defeats future APS radars under stressing engagement conditions in dynamic testing. By the end of FY03, demonstrate in live flight tests final flight prototypes of a CAPS device that defeats both current and future threat APS; and, through simulations, demonstrate the robustness of the capability to achieve defeat in 95 percent of engagements (TRL 6).

Supports: MHF/CM, Javelin, TOW.

TSO	TRADOC POC	STO Manager
Mary Miller	COL Frank Stone	Donald E. Lovelace
SAAL–TT	DCD USAIC	AMCOM AMRDEC
(703) 601–1543	(706) 545–1515	(256) 876–8609
329–1543	235–1515	746–8609

III.WP.2000.03—ADVANCED LIGHT ARMAMENTS FOR COMBAT VEHICLES. The purpose of this STO is to design, develop, and demonstrate optimum ammunition components in bursting munitions and novel KE long rods for 30- to 40-mm applications that would provide enhanced antiarmor and antipersonnel effects for ground combat vehicles. Bursting ammunition enhancements will focus on development, test, and evaluation of advanced fuzing and warhead lethality. KE ammunition enhancements will focus on leveraging large-caliber novel penetrator concept evolution for defeat of applique protected targets and increasing behind-armor effects.

In FY00/01, develop and demonstrate 30- to 35-mm novel KE penetrator concepts for defeat of advanced threat targets and enhanced behind-armor effects; and complete bursting munitions fuze technology assessment and simulated high-g functional evaluation. In FY01, complete detailed design of integrated 30-mm bursting munition warheads and fuzing; conduct full-up demonstration of 30-mm KE penetrator defeat capability against selected targets with 30 percent increase in behind-armor effects; and transition 30- to 35-mm KE designs to AAAV PM customers (TRL 4). In FY02, demonstrate 4X increase in 30-mm bursting munition projectile antipersonnel lethal area and complete integrated weapon/munition fuze setting interface designs. Demonstrate full-up 40-mm KE cartridge defeat of FCS threat targets (TRL 5). In FY03, demonstrate integrated 30-mm and 40-mm Supershot bursting munition projectile concepts, weapon/bursting munitions functionality, and 40-mm Supershot KE penetrator projectile package concept defeat of threat targets (TRL 6).

Supports: Bradley, FCS.

TSO
John Appel
SAAL–TT
(703) 601–1537
329–1537

TRADOC POC
COL Frank Stone
USAIC
(706) 545–1515
835–1515

STO Manager
Steven Liss
ARDEC
(973) 724–6968

III.WP.2001.01—RESPONSIVE ACCURATE MUNITION MODULE (RAMM). This STO develops a mortar-based, lightweight firing platform that can instantly respond and remotely conduct fire missions. This demonstrator will provide unique operational utility for noncontiguous combat, rapid force projection, rear-area combat support, and manned or unmanned operation; and will potentially offer an alternative to antipersonnel mines, with immediate and highly accurate response to battlefield sensor data. Upon receipt of target coordinates, RAMM will perform ballistic computations, self-deploy, align the tube, and automatically load and fire while maintaining a 360-degree traverse capability. With its self-orienting capability, coupled with current munitions and future guided rounds, RAMM will be a precision first-round-on-target system. Technology drivers include lightweight structural materials and manufacturing techniques, high speed, robust gun drives and accompanying software, and barcode ammunition inventory processing to complement the ammunition/loader magazine subsystem.

By FY01, produce the concept and initiate design of the module, autoloader magazine, and control software (TRL 4). By the end of FY02, complete the design of the module and autoloader magazine (TRL 4). By FY03, commence fabrication of RAMM and conduct a battlefield performance analysis (TRL 5). By the end of FY04, completed fabrication and subsystem testing (TRL 6). By FY05, complete final software and integrate it into a suitable carrier. The effort will conclude with a full-scale demonstration (TRL 7).

Supports: FCS.

TSO	TRADOC POC	STO Manager
John Appel	MAJ Wood	Anthony Franchino
SAAL–TT	HQ, TRADOC	ARDEC
(703) 601–1537	(757) 788–3849	(973) 724–3254
329–1537	680–3849	880–3254

SOLDIER SYSTEMS

III.SH.1997.01—MILITARY OPERATIONS IN URBANIZED TERRAIN (MOUT) ACTD. This STO demonstrates a full-spectrum, robust MOUT operational capability for small units that seamlessly integrates and aggregates the technologies of participating ATDs, TDs, and other technology developments in the areas of MOUT C^4I, survivability, engagement, and M&S. Robust communications for MOUT was pursued through contract options with DARPA's SUO Program. Joint field exercises were conducted with participation by dismounted soldiers, SOF, and the USMC. Demonstrations will include tactically realistic scenarios that test individual and small-unit performance in stressful MOUT environments to assess the interoperability of the MOUT system of systems. M&S will be used to facilitate mission planning and rehearsal, and augment quantification of performance enhancements. Minimum goals include 50 percent increase in situational awareness at all levels and 20 percent increase in force survivability.

Through FY01 and FY02, provide follow-on technical support to MOUT ACTD residuals. This STO is an integrated component of the MOUT ACTD.

Supports: Upgrades to LW, DBBL, Infantry School, and BCBL(L).

TSO	TRADOC POC	STO Manager
Pamela Beatrice	Chris Kearns	Carol Fitzgerald
SAAL–TT	DBBL	SBCCOM/NSC
(703) 601–1558	(706) 545–6391	(703) 704–1427
329–1558	835–6391	654–1427

III.SH.1999.01—LOW-POWER, UNCOOLED INFRARED SENSOR. This program will demonstrate low-power sensor technology for upgrades to Land Warrior, Thermal Weapon Sight (TWS), OICW, OCSW, Javelin Antitank Weapon System, and Driver's Vision Enhancer (DVE). Horizontal technology objective will increase capabilities across the dismounted force with a significant reduction in acquisition and sustainment costs. The STO product will be a compact weapon sight that incorporates an improved generation of uncooled IR technology and provides a pilot demonstration of an integrated power management architecture. The improved uncooled IR technology will provide a 25–30 percent improvement in performance over the current technology. Smart power management, low-power electronics architecture, and uncooled sensor technology will dramatically reduce power consumption. This reduction in power consumption, combined with a next-generation primary power source, will allow execution of a 72-hour mission without battery replacement.

By FY99, defined integrated power management architecture. In FY00, defined focal plane, image processing, and image stabilization requirements to meet Javelin Command Launch Unit range performance. By FY01, complete design of low-power electronics and power management to reduce power consumption by 60 percent versus the current TWS (i.e., from 8 W to 3 W) (TRL 4). By FY02, integrate advanced uncooled sensor, low-power display, and advanced primary power source into a 3-pound weapon sight prototype that exceeds performance requirements for the TWS heavy (5.4 pounds) (TRL 5). By FY03, deliver low-power uncooled IR sensor for user demonstrations and evaluations (TRL 5).

Supports: LW, TWS, Javelin, OICW, OCSW, DVE.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	Chris Kearns	David Randall
SAAL–TT	DBBL	CERDEC/NVESD
(703) 601–1546	(706) 545–6391	(703) 704–1159
329–1546	835–6391	654–1159

III.SH.2000.01—FUTURE WARRIOR TECHNOLOGY INTEGRATION. This program will integrates, demonstrates, and transitions technology upgrades for the Land Warrior system. System cost reduction, reduced power, and increased functionality without increased weight are the key goals for this program.

In FY00, completed transition of integrated navigation and LW CID capabilities into the baseline LW system. Also in FY00, developed tethered LW interfaces with the OICW and Javelin. By the end of FY01, upgrade baseline production LW systems, demonstrate and transition technology insertions (e.g., OICW and Javelin interfaces with a frame latency of less than three, medical monitoring, emerging commercial electronics and software that require 10 percent less power than baseline LW). By the end of FY02, demonstrate interoperability with tactical engagement simulation and evaluate advanced soldier displays, sensors, and high-density power sources to determine potential for capability enhancements. Participate in DARPA SUO/Situation Awareness Systems (SAS) and GloMo operations evaluations. By the end of FY03, measure SUO/SAS and GloMo technology performance within the LW platform, and transition most viable technologies. Demonstrate the viability of an advanced combat uniform system, including an integrated personal area network.

TSO	**TRADOC POC**	**STO Manager**
Pamela Beatrice	Chris Kearns	John Munroe
SAAL–TT	DBBL	NSC/SBCCOM
(703) 601–1558	(706) 545–6391	(508) 233–5813
329–1558	835–6391	256–5813

BIOMEDICAL

III.ME.1996.02—DRUG TO TREAT MULTIDRUG-RESISTANT AND SEVERE AND COMPLICATED MALARIA. The goal of this program is to develop and transition a drug to treat multidrug resistant and severe, complicated malaria.

In FY00, completed preclinical testing, filed an investigational new drug (IND) application with the FDA, and transitioned to advanced development (Milestone B) an oral drug formulation for the treatment of multidrug-resistant malaria. By the beginning of FY02, complete all studies necessary for submission of a new drug to FDA to permit advanced development of an intravenous drug formulation for the treatment of severe and complicated malaria.

Supports: AMP, Medical Annex O, "Project, Sustain, and Protect the Force: The Medical Threat Facing a Force Projection Army, (1994); TR97–026, Deployability; TR97–044 Survivability—Personnel; aligns with DTO MD.04, Antiparasitic Drug Program.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Herbert Russakoff	COL Charles Hoke
SAAL–TM	CSSBL	USAMRMC
(703) 601–1532	(804) 734–0599	(301) 619–7567
329–1532	687–0599	343–7567

III.ME.1996.03—MEDICAL COUNTERMEASURES FOR FILOVIRIDAE. This STO develops medical countermeasures against the biological warfare (BW) threat of Filoviridae, which includes Marburg virus and Ebola virus.

By FY01, transition to advanced development vaccine candidates effective against lethal aerosol challenge of Marburg and Ebola viruses. By FY01, evaluate immunoglobulin/monoclonal antibodies for passive immunization regiments for short-term protection and treatment; and evaluate antiviral compounds for effectiveness in short-term protection and treatment.

Supports: AMP, Medical Annex O, "Project, Sustain, and Protect the Force by Development of NBC Agent Preventive Measures"; provides for the exploration, demonstration, and validation of biological defense vaccines as outlined by the DEPSECDEF (26 Aug 91) and JROC (31 Aug 92).

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	CPT Ensor	Dr. Carol Linden
SAAL–TM	CSSBL	USAMRMC
(703) 601–1532	(706) 545–5994	(301) 619–7439
329–1532	835–5994	343–7439

III.ME.1997.01—MEDICAL COUNTERMEASURES FOR ORTHOPOX VIRUSES. This program develops medical countermeasures against the BW threat of variola, the causative agent of smallpox.

In FY97, confirmed the use of an animal model for the purpose of demonstrating the efficacy of the current licensed vaccine against aerosol-delivered variola. In FY98, performed relevant preclinical testing of new cell culture-derived vaccinia vaccine directed toward variola. In FY99, developed rapid and highly specific diagnostic devices for clinical specimens. In FY00, explored the feasibility of using human monoclonal antibodies to replace vaccinia immune globulin. By FY01, screen and identify effective antiviral drugs for post-exposure treatment. [*Note:* all of the studies conducted at the U.S. Army Medical Research Institute for Infectious Diseases (USAMRIID) will not use variola itself; instead the studies will employ an appropriate orthopox virus substitute.]

Supports: AMP, Medical Annex O, "Project, Sustain, and Protect the Force by Development of NBC Agent Preventive Measures"; provides for the exploration, demonstration, and validation of biological defense vaccines as outlined by the DEPSECDEF (26 Aug 91) and JROC (31 Aug 92).

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	Chris Kearns	Dr. Carol Linden
SAAL–TM	CSSBL	USAMRMC
(703) 601–1532	(706) 545–6391	(301) 619–7349
329–1532	835–6391	343–7349

III.ME.1998.01—MULTIAGENT VACCINES FOR BIOLOGICAL THREAT AGENTS. This program develops vaccine candidates that will concurrently provide protective immune response against a range of biological threat agents. The objective is to identify technologies that would permit multiple immunogens or nucleic acid-based vaccine candidates to be combined in a single preparation with the endpoint of simultaneously immunizing recipients against multiple BW threats.

In FY00, demonstrated the feasibility of these approaches in appropriate animal models. By FY02, transition to advanced development (Milestone B) a vaccine that protects 90 percent or more of immunized animals from death or incapacitation by specific agents, as appropriate, following exposure to aerosol delivery of agents at doses equivalent to those anticipated under operational settings.

Supports: AMP, Medical Annex O, "Project, Sustain, and Protect the Force by Development of NBC Agent Preventive Measures"; provides for the exploration, demonstration, and validation of biological defense vaccines as outlined by the DEPSECDEF (26 Aug 91) and JROC (31 Aug 92).

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	Chris Kearns	Dr. Carol Linden
SAAL–TM	CSSBL	USAMRMC
(703) 601–1532	(706) 545–6391	(301) 619–7349
329–1532	835–6391	343–7349

III.ME.1998.02—COMMON DIAGNOSTIC SYSTEMS FOR BIOLOGICAL THREATS AND ENDEMIC INFECTIOUS DISEASES. This STO develops diagnostic assays and reagents that will provide rapid laboratory diagnosis for a broad array of biological threats and infectious diseases using common diagnostic technologies. The objective is to identify technologies that allow for forward and confirmatory laboratory diagnosis regardless of the etiological agent.

In FY98, demonstrated the feasibility of common diagnostic systems for biological threats and infectious diseases; and identified genetic and immunological targets for emerging diagnostic systems technology for biological threats and infectious diseases. By FY02, transition to advanced development a device capable of identifying nucleic acids from a range of infectious diseases and biological warfare agent in clinical specimens (TRL 7).

Supports: DEPSECDEF guidance (26 Aug 91); JROC guidance (31 Aug 92); CSSBL; DMBL; TR97–044, Survivability—Personnel.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	CPT Ensor	Dr. Carol Linden
SAAL–TM	CSSBL	USAMRMC
(703) 601–1532	(706) 545–5994	(301) 619–7439
329–1532	835–5994	343–7439

III.ME.1999.02—JOINT MEDICAL OPERATIONS—TELEMEDICINE ACTD. This STO provides the regional CINC and JTF commander a capability to defeat time and distance obstacles for cost-effective joint health support in operational theaters.

In FY99, completed Demonstration 1 to determine operational utility and interoperability of medical and communication equipment. In FY00, completed Demonstration 2 to evaluate integrated concept of operations in capstone utility assessment. By FY01, transition to the field a leave-behind capability for the CINC surgeon or designated component surgeon. By FY02, transition to acquisition a Joint Medical Operations Telemedicine System or components thereof that will enhance operational effectiveness of Joint Expeditionary Forces, reduce attrition of forces, enhance joint commander's view of medical threats, and advance focused medical logistics.

Supports: MD97–002, Medical C^4I; MD97–003, Patient Treatment and Area Support; links to the *Defense Technology Area Plan* (DTAP)/Defense Technology Objective (DTO) (Chapter II) and the *Joint Warfighter Science and Technology Plan* (JWSTP).

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Warren Dixon	LTC Phylanne Prince
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–3388
329–1532	680–4413	343–3388

III.ME.2000.01—A MULTIANTIGEN, MULTISTAGE *PLASMODIUM VIVAX* MALARIA VACCINE. Malaria caused by *Plasmodium vivax* continues to be a high-priority threat facing military service members in many endemic areas worldwide. Current efforts are aimed at development of an effective vaccine to use in conjunction with a *Plasmodium falciparum* vaccine.

In FY00, initiated Good Manufacturing Practices (GMP) production of *P. vivax* vaccine plasmids. By FY01, complete GMP production, of *P. vivax* vaccine plasmids and submit an IND application. By FY02, complete preclinical testing and submit an IND for a recombinant protein vaccine. By FY03, complete testing of the multivalent, recombinant protein *P. vivax* vaccine; submit an IND for a multiantigen, multistage *P. vivax* vaccine. By FY05, complete efficacy trials of the multiantigen, multistage *P. vivax* vaccine and transition to advanced development.

Supports: TR97–026, Deployability; TR97–029, Sustainment; TR97–044, Survivability—Personnel.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Warren Dixon	COL Charles Hoke
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7567
329–1519	680–4413	343–7567

III.ME.2001.02—FIELD MEDICAL MONITORING AND THERAPEUTIC DEVICES FOR CASUALTY CARE. This STO significantly enhances the diagnostic and therapeutic capabilities of the combat medic and provides medical devices that greatly improve our ability to treat, monitor, and evacuate seriously wounded patients. It will virtually eliminate the need for oxygen bottle delivery on the battlefield.

By the end of FY01, produce prototypes of a 6-ounce detector that can measure pulse rate and respiration through clothing (vital signs monitor) (TRL 5), mission-oriented protective posture (MOPP), and body armor; a 20-pound portable life support package (Mini-STAT) (TRL 3); and a 3 -liter-per-minute, 10-pound oxygen generator (personal oxygen generator). By the end of FY02, complete preclinical validation testing of the Mini-STAT (TRL 6), the personal oxygen generator (TRL 6), and a pneumothorax detector (TRL 5). By the end of FY03, transition to advanced development the vital signs monitor (TRL 7), an integrated anesthesia device (TRL 7) to replace the current field draw-over anesthesia machine, and the personal oxygen generator (TRL 7). By the end of FY04, transition to advanced development the mini-STAT and complete clinical evaluations of the pneumothorax detector (TRL 6). By the end of FY05, transition to advanced development the pneumothorax detector (TLR 7).

Supports: DTO MD.NEW.02, Field Medical Monitoring and Therapeutic Devices for Casualty Care; MD97–003, Patient Treatment and Area Support; MD97–005, Far-Forward Surgical Support

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Warren Dixon	COL Robert Vandre
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7591
329–1532	680–4413	343–7591

CHEMICAL/BIOLOGICAL DEFENSE

III.BC.2001.01—ADVANCED INFRARED OBSCURANTS. The thrust of this STO is to use novel material technology to find a higher performing obscurant material in the mid and far infrared region of the electromagnetic spectrum.

By FY01, define particle characteristics of an ideal IR obscurant and determine the most efficient defeat mechanism for IR sensors (TRL 2). By FY02, determine what commercial processes exist or can be modified to produce candidate materials, and identify cost drivers for material production (TRL 3). By FY03, evaluate and select a new obscurant that will increase obscuring performance by a factor of four (TRL 4). By FY04, demonstrate a new obscurant screening material and a chamber method for evaluating its performance as an aerosol, and evaluate the applications of this advanced obscurant material in simulations to determine the percentage of increased survivability for the soldier (TRL 5). This technology will be applicable to infrared-screening smoke pots, grenades, artillery rounds, and vehicle self-protection. Its focus on increased performance could open the possibilities for an IR smoke pot, an IR hand grenade, and an IR screening artillery round. It would significantly reduce the logistics burden of a vehicle self-protection IR grenade.

TSO
Pamela Beatrice
SAAL–TT
(703) 601–1558
329–1558

TRADOC POC
LTC Robert Serino
MANSCEN
(573) 563–4078
676–4078

STO Manager
Jeff Hale
Edgewood CB Center/SBCCOM
(410) 671–2607
584–2607

ENGINEERING, COMBAT CONSTRUCTION, MOBILITY, AND COUNTERMOBILITY

III.EN.1996.01—RAPID TERRAIN VISUALIZATION (RTV) ACTD. The RTV ACTD integrates and demonstrates capabilities to rapidly collect and process (1) high-resolution digital terrain elevation data needed to accurately represent the 3D battlefield; (2) basic feature data such as roads, rivers, and vegetation required for military planning and analysis; and (3) corresponding high-resolution imagery for photo realism. These products provide the foundation to support a wide range of Army operations, including rapid response and force projection. The Army TRADOC has identified an operational requirement to generate and deliver these digital terrain products more rapidly—data coverage for a 20- by 20-km area within 18 hours, a 90- by 90-km area within 72 hours, and a 300- by 300-km area within 12 days. DoD does not currently have the ability to rapidly collect and exploit these critical digital topographic products. The RTV ACTD will demonstrate an infrastructure to collect, develop, and provide digital topographic data more rapidly to support military operations anywhere in the world. Specifically, the ACTD will demonstrate these capabilities for a 90- by 90-km area within 72 hours. An operational testbed will be established with the XVIII ABN Corps at Fort Bragg, NC, to demonstrate these capabilities in Army AWEs. Specific capabilities with significant military value to other Army and joint units can be provided to those units for additional evaluations.

Leave-behind capabilities will be provided to the XVIII ABN Corps beginning in FY99 and supported through FY01.

TSO	TRADOC POC	STO Manager
Bruce Zimmerman	COL Don Riley	Christian Moscoso
SAAL–TT	USA ES/MSBL	JPSD–RBV
(703) 601–1559	(573) 563–7959	(703) 704–1966
329–1559	676–7959	654–1966

III.EN.1997.01—ADVANCED MINE DETECTION SENSORS. This STO develops and field evaluates novel sensor technologies and signal processing techniques to overcome current deficiencies specifically in detecting lo3w and nonmetallic content mines, reducing false alarm rates and classifying detected targets. Technical goals are 95 percent probability of detection with false alarm rates less than 0.01 per square meter.

In FY99, designed, built, and assessed a novel, university-developed acoustic imaging technique for mine detection applications. Investigated electromagnetic induction technologies and associated algorithms for metallic mine identification and discrimination capabilities. In FY00, leveraged DARPA-funded nuclear quadrupole resonance (NQR) and chemical identification technologies for applications as scanning or confirmation mine detection sensors. Designed, built, and evaluated brassboard electromagnetic induction and acoustic technologies for improved false-alarm reduction (TRL 4). By FY01, build competing brassboard NQR, chemical, electromagnetic induction, and acoustic systems using design recommendations from prior field studies. Conduct field tests and evaluations of the resulting advanced mine detection sensor systems (TRL 5).

Supports: PM–MCD.

TSO	TRADOC POC	STO Manager
Rob Saunders	Brian C. Murphy	Kelly Sherbondy
SAAL–TT	Engineer School DCD	CERDEC/NVESD
(703) 601–1546	(573) 596–0139/37214	(703) 704–2448
329–1546	676–7214	654–2448

III.EN.1998.01—AREA DENIAL SYSTEMS (ADS). This STO demonstrates the capability of self-contained, semi-autonomous, long-standoff munitions that can defend an area by defeating, disrupting, and delaying vehicles that enter its battlespace. The ADS concept expands on the capabilities demonstrated under the Intelligent Minefield (IMF) STO, which concluded in FY97, by extending the effective range from 100 m to 1,000 m (100X increase in area coverage), and enhancing the operational utility through improved system employment and recovery. Like current land mines, ADS will enhance other weapon systems, but without the post-war threat to civilians and the associated demining problem.

In FY98, evaluated available sensor and communication technologies; defined tradeoffs, including countermine resistance; and developed a baseline design for hand-emplaced ADS. In FY99, evaluated alternative deterrent concepts (TRL 2). In FY00, built and tested prototype deterrent modules and investigated robotic platforms and alternative delivery and recovery methods (TRL 3/4). By FY01, conduct an integrated demonstration of hand-emplaced sensors and deterrent modules (TRL 4).

Supports: Objective Force.

TSO	TRADOC POC	STO Manager
John Appel	COL William McCoy	George E. Lutz
SAAL–TT	U.S. Army Engineer School	AMSTA–AR–FS
(703) 601–1537	(573) 563–4086	(201) 724–7848
329–1537	676–4086	880–7848

III.EN.1999.01—LIGHTWEIGHT AIRBORNE MULTISPECTRAL MINEFIELD DETECTION (LAMD). This STO explores an innovative concept and technology to support a lightweight airborne standoff minefield and nuisance mine detection capability. It will investigate a variety of new component and focal plane array (FPA) technologies such as 3- to 5-μm staring FPAs, multispectral/hyperspectral FPAs, passive polarization, passive millimeter wave (MMW), foliage penetration radar, SAR, active sources, sensor fusion, and electronic stabilization to support a lightweight, limited capability for future tactical UAVs.

In FY98, acquired mine signature data and baseline algorithm performance; and initiated phenomenology investigation. In FY99, completed study efforts, initiated procurement of sensor testbed components, and began detailed multispectral algorithm development. In FY00, initiated development of lightweight, multispectral airborne system for UAV integration, performed near-term user demonstration, and continued algorithm development. By FY01, complete sensor build, initiate system integration with the UAV system, and demonstrate algorithm improvements (TRL 6). By FY02, complete system

integration with the UAV system and conduct system test and evaluation (T&E) (TRL 6). By FY03, continue T&E for SDD risk reduction.

Supports: Objective Force, PM–FCS.

TSO
Rob Saunders
SAAL–TT
(703) 601–1546
329–1546

TRADOC POC
Brian C. Murphy
Engineer School DCD
(573) 596–0139/37214
676–7214

STO Manager
Ron Rupp
CERDEC/NVESD
(703) 704–2442
654–2442

III.EN.2000.01—FALSE ALARM REDUCTION FOR IMPROVED OPERATIONAL TEMPO (OPTEMPO). The virtual elimination of false alarms from mine detection systems is critically needed to provide acceptable rates of advance. Confirmation sensors, a new concept for mine detection, will demonstrate dramatically reduced false alarm rates (potentially to zero) and, in combination with other sensors, will permit operationally significant rates of advance. Route clearance operations will be much faster and safer than current methods, which entail time-consuming manual investigation of "empty holes." The confirmation sensor concept will leverage DARPA's outstanding technology advancements in explosives detection techniques, especially NQR, and maturing sensor technologies from the Advanced Mine Detection Sensors (AMDS) STO. In this concept, confirmation sensors, such as NQR, and primary sensors, such as those under development in the Block 0 Ground Standoff Mine Detection System (GSTAMIDS) program, will be integrated with advanced signal processing techniques, automatic target recognition (ATR) algorithms, and sensor fusion techniques on a single demonstration platform for test and experimentation.

By FY01, field-evaluate NQR and AMDS technologies to assess performance for immediate integration into GSTAMIDS Block 1, and establish initial confirmation sensor technical benchmark. By FY02, conduct field evaluation of AMDS technologies, including laser doppler vibrometry and time domain eddy decay analysis, and implement developmental improvements (TRL 4/5). By FY03, downselect high-payoff techniques, establish intermediate technical benchmarks, and continue field evaluation efforts (TRL 5). By FY04, complete test-fix-test cycle. Conduct final field tests with a field demonstration at both arid and temperate test sites for metrics, and transition prototype design, techniques, and systems for incorporation into GSTAMIDS Block improvements (TRL 6).

Supports: Objective Force, PM–MCD, MMBL.

TSO
Rob Saunders
SAAL–TT
(703) 601–1546
329–1546

TRADOC POC
LTC Gazzano
DCD, Engineer School
(573) 563–6190
676–6190

STO Manager
Steve Bishop
CERDEC/NVESD
(703) 704–1037
654–1037

LOGISTICS

III.LG.1998.01—REFORMING DIESEL (COGENERATION). This STO develops technology reform diesel fuel into a versatile gaseous fuel that can be cleanly and reliably burned in high-efficiency, gas-fired kitchen equipment and that can be used to cogenerate electric power.

In FY98, demonstrated a diesel fuel reformer with an ability to convert diesel fuel into gaseous fuels (H2 and C1 to C4) at a rate of 3 gallons per hour and a yield of 70 percent high heat value. In FY99, demonstrated a yield of 90 percent. By the end of FY01, integrate the cogenerator in a field kitchen that will enable the preparation of high-quality meals efficiently (50 percent fuel reduction), quietly (10-dB noise reduction), and reliability (50 percent increase in MTBF) (TRL 6).

Supports: Joint Service Food Program: Advanced Development RJS2/63747/D610—Food Advanced Development; Engineering Development RJS2/64713/D548—Military Subsistence Systems; Army Field Feeding Equipment 2000 (MNS); Quartermaster School.

TSO	TRADOC POC	STO Manager
Pamela Beatrice	MAJ Jeff Woods	Don Pickard
SAAL–TT	Quartermaster School	NSC
(703) 601–1558	(804) 734–0609	(508) 233–5036
329–1558	687–0609	256–5036

III.LG.1998.02—ENHANCED COASTAL TRAFFICABILITY AND SEA STATE MITIGATION ATD. This STO demonstrates the impact of recently developed technology for enhancing logistics-over-the-shore (LOTS) and joint LOTS (JLOTS) operations, including (1) a rapidly installed breakwater (RIB) that enables Sea State 3 (significant wave heights from 0.9 to 1.52 m) operability at offshore anchorages used during LOTS and JLOTS operations; and (2) use of a sand-fiber stabilization system, plastic hex mat, and fiberglass mat for rapid beach preparation and sustained trafficability during JLOTS operations. The goal of this ATD is to successfully deploy an ocean-scale RIB that creates a sheltered area within its lee by reducing Sea State 3 conditions to Sea State 2 (significant wave heights less than 0.9 m) or lower, and to demonstrate improve techniques for rapidly stabilizing beach soils for offload sites to the infrastructure.

In FY00, completed engineering design for full-scale breakwater(s) based on detailed engineering analyses, and laboratory and 1/4-scale field tests; provided the capability to rapidly stabilize beach sands with minimum logistic burdens and reduced engineer equipment. By the end of FY02, demonstrate rapidly installed breakwaters for reduction of wave conditions in sea states up to the lower end of Sea State 4 IR by 50 percent, and demonstrate improved techniques to rapidly stabilize soft soils for roads and material storage areas associated with LOTS operations (TRL 7).

Supports: PM—Force Projection Enabling Systems (PM–FPES).

TSO	TRADOC POC	STO Manager
Jeff Messmore	James Sova	Dr. Jimmy Fowler
SAAL–TR	TRADOC HQ	CEERD
(703) 601–1523	(757) 788–3005	(601) 634–3026
329–1523	680–3005	

III.LG.1999.01—LOGISTICS COMMAND AND CONTROL (LOG C^2) ATD. This STO revolutionizes tactical sustainment for the Army through development, demonstration, and transition of products that will pave the way for the revolution in military logistics through logistics information dominance. The objective is to enable the light strike force commander to shorten the operation decision cycle and to optimize resources. This objective will be accomplished through a demonstration of complete access to automated logistics data down to the distributor unit level. The Log C^2 ATD will include transition of products to the program manager, Global Combat Service Support—Army (GCSS–A), and the PM, Combat Service Support Control System (CSSCS).

In FY99, determined logistics operations planning criteria with DISCOM commanders, Division G4, and S4. Also in FY99, held a conference to determine CSS data relevant to combat and CSS commanders' decision cycle. In FY00, demonstrated Force XXI battle command brigade and below ($FBCB^2$) automatic data exchange to the GCSS–A in response to logistics operations planning criteria (TRL 4), and demonstrated a decision support software tool for combat commanders to plan crewing (accessing personnel data and commander's observations). The Log C^2 ATD will participate in Joint Contingency Force. In FY01, demonstrate deliberate COA software and intelligent agent "alerts" for CSS commanders and staff (TRL 7). Also in FY01, demonstrate decision support tool software that optimizes weapon system management based on GCSS–A (Classes III, V, and VII) data (TRL 4), and participate in Prairie Warrior. In FY02, demonstrate GCSS–A to CSSCS online data exchange, and participate in National Training Center rotation (TRL 7). In FY03, demonstrate reconstitution decision support software, and transition COA software and decision support tool to CSSCS (TRL 7).

Supports: GCSS–A, CSSCS, $FBCB^2$.

TSO	TRADOC POC	STO Manager
Rob Saunders	MAJ Lary Chinowsky	Michael Badger
SAAL–TT	CASCOM	CERDEC/C2SID
(703) 601–1546	(804) 734–2285	(732) 532–0492
329–1546	687–2285	992–0492

III.LG.1999.02—WIDE-SPAN AIRBEAM SHELTER FOR LOGISTICS APPLICATIONS. This STO demonstrates a high-pressure airbeam technology with the ability to span a cross section exceeding 60 feet—an increase of 100 percent over existing capabilities—which will allow for the development of shelters for the field expedient maintenance of aircraft as well as the rapid establishment of logistical functions such as storage and distribution at ports and across the battlefield.

In FY99, defined the optimized textile architecture for airbeams capable of supporting the structural loads of wide-span arches. In FY00, identified the best performing configuration through the fabrication and testing of preliminary airbeam prototypes. By the end of FY01, demonstrate the ability of an airbeam-supported structure to span a cross section exceeding 60 feet in width.

Supports: Quartermaster School, Aviation School, ORD for the Aviation Maintenance Shelter.

TSO	TRADOC POC	STO Manager
Pamela Beatrice	MAJ Jeff Woods	Jean Hampel
SAAL–TT	Quartermaster School	NRDEC
(703) 601–1558	(804) 734–0609	(508) 233–4692
329–1558	687–0609	256–4692

III.LG.2000.02—COMBAT RATIONS FOR ENHANCED WARFIGHTER LOGISTICS. This STO develops a logistically focused ration system that tailors the components to the combat situation and radically improves mobility using advanced processing and packaging technologies that stabilize ration components, impart both fresh-like appearance and nutritional value, and reduce food waste through enhanced acceptance and a sensor-based ration selection and logistics tracking system.

In FY00, designed a ration module that is compact, complete, and consumable OTM, with a targeted 20 percent increase in key metric of ration kcal consumed per day divided by the total weight or volume of rations supplied (including packaging) per person per day. By FY01, integrate into the design all appropriate packaging concepts for ensuring high-quality rations in extreme environments and jointly with U.S. Army Research Institute of Environmental Medicine and ARL Human Resources and Engineering Directorate (HRED) developed studies to model impact of increased ration consumption in extended operations tasks with performance indicators. By FY02, demonstrate fiber optic or remotely interrogated quality-status sensors and time-temperature integrators to interface with DoD Total Asset Visibility Systems. By FY03, integrate a ration selection model that considers nutritional and energy requirements for a given scenario and then specifies what components are to be taken and when to consume them.; and demonstrate a 30 percent increase in the metric for daily kcal consumed/ration weight and increasing consumption (TRL 6). Benchmark best industrial practices for metrics of cost effectiveness and supply rates of Class 1 items.

TSO	TRADOC POC	STO Manager
Pamela Beatrice	MAJ Jeff Woods	Dr. P. Dunne
SAAL–TT	Quartermaster School	NSC/SBCCOM
(703) 601–1558	(804) 734–0609	(508) 233–5514
329–1558	687–0609	256–5514

III.LG.2000.03—PRECISION ROLL-ON/ROLL-OFF AIR DELIVERY. Advanced key technologies are needed for air delivery of cargo with precise accuracy over extended distances. This STO investigates and demonstrates a system of advanced technologies focused on substantially improving current capabilities across the spectrum of airdrop operations. These technologies include (1) advanced pneumatic muscle and airbag technologies to provide a roll-on/roll-off quick-airdrop capability for heavy cargo; (2) air-inflated parafoils and 3D weaving techniques to provide a long-range, autonomous airdrop capability with the option to deliver separate and distinctive payloads to multiple locations; and (3) controllable cluster parachutes for high-altitude, accurate (50–100 meters CEP) "just-in-time" delivery to provide low-cost, precision resupply. In order to achieve this as well as other airdrop systems development, airdrop model tools are required to optimize parachute designs, and to reduce development time and costs. Currently, there is a lack of high-fidelity parachute/airdrop system design tools. This STO will provide an integrated,full function prediction/analytical capability meeting the Objective Force timeline.

In FY00, identified and analyzed candidate systems for a long-range, autonomous airdrop capability (TRL 3). By the end of FY01, fabricate and test the long-range autonomous system and the high-altitude just-in-time delivery system (TRL 4); and design the pneumatic/airbag system and the high-altitude cluster control system (TRL 5). By the end of FY02, demonstrate the roll-on/roll-off capability for 15,000–20,000-pound payload providing a 60 percent decrease in labor intensive rigging time (TRL 6). By the end of FY03, demonstrate an autonomous airdrop capability (goal of 20–40 miles offset) with the

operation to deliver separate and distinct payloads (up to 10,000 pounds total) to multiple locations (TRL 6). Complete development of validation tools (TRL 5). By the end of FY04, demonstrate controlled G–11 parachutes with a 10,000-pound payload from high altitude and with completely autonomous control and precise landing (TRL 6). Complete model development and refinement. By the end of FY0-5, complete model validation (TRL 6).

Supports: RML.

TSO	TRADOC POC	STO Manager
Pamela Beatrice	MAJ Jeff Woods	E. Doucette
SAAL–TT	Quartermaster School	NSC/SBCCOM
(703) 601–1558	(804) 734–0609	(508) 233–4636
329–1558	687–0609	256–4636

PERSONNEL PERFORMANCE

III.PE.1996.01—TRAINING STRATEGIES FOR THE OBJECTIVE FORCE. The focus of this STO is to develop and demonstrate new training and evaluation technologies that prepare operators and commanders to take maximum advantage of evolving digitized C^3 systems. This training research will incorporate the use of virtual, constructive, and live simulations to demonstrate and evaluate selected prototype training techniques.

In FY98, completed design of prototype staff training packages that use advanced digital technology. In FY99, evaluated performance assessment tools for the digitized battlefield. Additional advanced training techniques and strategies will be demonstrated and evaluated in developmental simulations.

Supports: TRADOC, U.S. Army USAARMC&S, MBBL, III Corps.

TSO	**TRADOC POC**	**STO Manager**
M. A. Fischl	MG George Harmeyer	Barbara Black
SAAL–TR	Director, U.S. Army Armor	ARI
(703) 601–1522	(502) 624–7555	(502) 624–3450
329–1522	464–7555	464–3450

SPACE

III.SS.1997.01—BATTLEFIELD ORDNANCE AWARENESS (BOA). This program demonstrates a near-real-time ordnance reporting system using onboard processing collocated with the sensor(s). U.S. warfighters currently have limited, ground-based means to identify enemy and friendly shooters and the associated detonations. With BOA, an overhead staring sensor complements existing ground-based systems by collecting data on the time, location, and intensity of ordnance events such as muzzle flashes, missile firings, and warhead detonations. These data could be compared with a database of weapon "signatures" to provide the warfighters with near-real-time comprehensive information on targeting, battle damage assessment (BDA), ammunition consumption, and enemy weaponry. This technology will provide near-real-time BV of friendly and enemy ordnance fires, including cruise missile launches. It addresses the need to target ordnance delivery for counterfire purposes—a major battlefield deficiency. While systems exist to locate and track vehicle traffic and radio frequency transmitters for intelligence preparation of the battlefield, there are no systems that report type, time, and sightings of either friendly or enemy ordnance. BOA will identify the ordnance by type and provide position information for counterfire opportunities, as well as BDA, friendly force ordnance inventory, information for dispatch of logistical and medical support, and search and rescue. It also has the potential to type-classify launch systems using the time domain intensity information in specific spectral bands. Advanced processor technology will be used with state-of-the-art staring FPAs to provide critical information to battlefield commanders.

In FY97, acquired a limited set of ordnance data by type and developed preliminary algorithms for target ID. In FY98, developed the processing architecture for near-real-time processing of the ordnance data, and collected data on key foreign systems. In FY99, continued development of algorithms for real-time classification, ID, and multiple events. By FY00, collected ordnance data under a variety of environmental conditions, and developed targeting, ID, and simultaneous events software (TRL 6). In FY01, demonstrate near-real-time airborne ordnance reporting, complete experimentation supporting the definition of ordnance reporting requirements for space sensors, and define the Army technical requirements to provide a battlespace characterization capability to the warfighter with space platforms (TRL 7). Transition technology to the Space-Based Infrared System, national platforms, and Army PEO–GCSS.

Supports: USFK, CENTCOM, EUCOM, PACOM, D&SABL, Objective ForceIntel Center, PEO–GCSS.

TSO	TRADOC POC	STO Manager
Ron Norris	Maj. Mo Minchew	Kaye Blankenship
SAAL–TS	D&SABL	SMDC
(703) 601–1553	(405) 442–2928	(256) 955–3525
329–1553	639–2928	645–3525

III.SS.1998.01—OVERHEAD SENSOR TECHNOLOGY FOR BATTLEFIELD CHARACTERIZATION. This program develops and demonstrates advanced overhead sensor technologies for wide-area battlefield force detection, discrimination, and target ID in near real time, and reduces platform data communications downlink and ground processing Army requirements. Technologies focus on passive optical sensors using spectral, polarimetric, and FPA requirements. The initial sensor is baselined for UAV testing and applications. The final sensor configuration will be integrated onto the U.S. Air Force Mighty-Sat platform to be

manifested in the DoD Tri-Service Space Test Program. This provides opportunities for the Army to define operational and technical requirements for next-generation optical space sensors and associated ground processing capabilities in support of the Army warfighting goals. Sensor bands in the 0.4- to 2.5-μm, 3- to 5-μm, and 8- to 12-μm regions with hyperspectral output will be investigated. Specific technologies exploited include approaches to improve area coverage; on-FPA signal processing techniques to exploit spectral/polarimetric signatures to achieve high-performance autocueing, hyperspectral, spatial, and temporal signature processing; and wide FOV imagery. These sensor technologies will provide wide-area coverage of the battlefield, robust detection, and targeting data while remaining within current Army C^4I data rates.

In FY99, packaged and configured baseline sensor for UAV and space applications, and conducted initial demonstration of on-FPA processing of spectral data. In FY00, demonstrated a hyperspectral sensor with smart focal plane processing in the 1- to 2.5-μm, 3- to 5-μm, and 8- to 12-μm wavebands; demonstrated improved cueing and clutter rejection via polarization and on-FPA processing using ground test; and analyzed and incorporated appropriate warfighter hyperspectral technologies (TRL 5/6). By FY01, demonstrate on-chip neomorphic processing, and hyperspectral spatial and temporal signature processing with sensor using airborne testing (TRL 6). By FY02, field-test an integrated sensor on a high-altitude UAV and measure performance against stated objectives (TRL 7). In FY03, begin integration of advanced space sensor technologies into the Mighty-Sat platform for subsequent launch and demonstration in the DoD Tri-Service Space Test Program.

Supports: USASMDC, NVESD, and U.S. Air Force Research Lab Project; Objective Force; SMDBL; BCBL; D&SABL; CCAWS.

TSO	**TRADOC POC**	**STO Manager**
Ron Norris	COL Peter Thomson	Ben Kerstiens
SAAL–TS	USAADAC	SMDC
(703) 601–1553	(915) 568–1392	(256) 955–1769
329–1553	978–1392	645–1769

III.SS.1999.01—SPACE SURVEILLANCE. This STO develops and demonstrates a transportable battlefield area-of-operations capability that determines the status and operation of threat systems.

In FY00, developed phenomenology document and completed conceptual design (TRL 3). By end of FY01, complete development of threat database and assessment algorithms (TRL 4). By end of FY02, demonstrate automated near-real-time threat configuration assessment (TRL 5). By end of FY03, demonstrate a laboratory integrated capability (TRL 5/6). By end of FY04, demonstrate a system integrated field test and transition to ground-based radars (TRL 7). This project will provide the theater commander with dominate-the-battlespace knowledge.

Supports: PEO AMDand other classified space control projects.

TSO	**TRADOC POC**	**STO Manager**
Ron Norris	COL Peter Thomson	Rodger Qualls
SAAL–TS	USAADAC	SMDC–TC–Y
(703) 601–1553	(915) 568–1392	(256) 955–1479
329–1553	978–1392	645–1479

APPLIED RESEARCH (TECHNOLOGY DEVELOPMENT) (CHAPTER IV, VOLUME I)

AVIATION

IV.AV.1997.01—ADVANCED ROTORCRAFT AEROMECHANICS TECHNOLOGIES (ARCAT). The technical objectives of this program are to increase maximum blade loading by 8 percent, increase rotor aerodynamic efficiency by 3 percent, reduce aerodynamic adverse forces by 5 percent, reduce aircraft loads and vibration loads by 20 percent, reduce acoustic radiation by 4 dB, increase inherent rotor lag damping by 33 percent, and increase rotorcraft aeromechanics predictive effectiveness to 65 percent. Results will be achieved by addressing technical barriers of airfoil stall; high, unsteady airloads; blade–vortex interaction (BVI); highly interacting aerodynamics phenomena; complex aeroelastic and structural dynamics characteristics; and limited analytical prediction methods and design tools. Concepts include application of on-blade active control to increase rotor performance and aerodynamic efficiency; reduce BVI noise, blade loads, and vehicle vibration at the source; optimize the configuration geometry of the rotor blade and introduce advanced airfoil concepts to increase aerodynamic efficiency, and maximum blade loading; and vigorously integrate and validate advanced analytical tools, such as computation fluid dynamics (CFD), finite-element structural models, and advanced computational solution techniques to effectively advance rotorcraft aeromechanics technology.

In FY97, exploited concepts for smart materials active on-blade aerodynamic controls. In FY98, simulated high-lift, low-energy, periodic-blowing airfoil design; evaluated practical Navier–Stokes CFD solver for rotorcraft interaction aerodynamics; and demonstrated model-scale, on-blade active control rotor concepts for reduced vibration and noise. In FY99, demonstrated integrated CFD/finite-element structures rotorcraft modeling. In FY00, demonstrated concepts to eliminate conventional rotor lag dampers through the application of smart structures. Achievement of aeromechanics technology objectives will contribute to rotorcraft system payoffs in range, payload, cruise speed, maneuverability/agility, reliability, maintainability, and reduced RDT&E, procurement, and O&S costs (TRL 4).

Supports: RAH–66, AH–64, and fielded system upgrades; next-generation cargo vehicles (FTR); collaborative technologies; and OCRs for EELSBL, CSSBL, D&SABL, DBBL, and MTDBL. Contributes to RWV TDA objectives, goals, and payoffs.

TSO	TRADOC POC	STO Manager
Mary Miller	Ted Hundley	Wayne Mantay
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–1465	(757) 864–3953
329–1543	558–1465	927–3953

IV.AV.1999.01—VARIABLE-GEOMETRY ADVANCED ROTOR TECHNOLOGY (VGART). This STO develops the high-payoff 6.2 variable-geometry rotor technology to transition to the fielded fleet, and the Objective Force 6.3 rotor system demonstration. The high-risk rotor concepts, currently under investigation in the ARCAT STO, have critical subcomponent (e.g., on-blade actuators) and scaling barriers that must be addressed if application to an Objective Force-size air platform is to be successful. Immediate technical benefits from the advanced concepts include 30 percent reduction in rotorcraft vibration, and rotor max blade loading increases of 10 percent. Long-term applications such as FTR/Objective Force offer even greater benefits. The concept mechanisms have never been scaled to the challenging FTR and Objective

Force environment. Successful lab demonstration of the critical components will allow for leap-ahead platform performance and affordability.

In FY99, completed detailed design studies and joint-service issue assessments. Completed subcomponent fabrication in FY00. Complete benchtests in FY01. By the end of FY01, have downselect criteria and subcomponent fidelity available for application to a flight demonstrator. (TRL 5) The Objective Force enhancement resources will be used for large-scale critical component fabrication (FY99–00), testing (FY01), and analysis for the promising concept of the variable diameter rotor.

Supports: FOCs AV98–007, AV98–008, AV98–009, AR97–002, CS98–005, DSA97–018, FPC98–04, FPC98–06, OD98–012, QM98–001, TC98–006; fielded system upgrades; FTR; contributes to RWV TDA objectives, goals, and payoffs.

TSO	**TRADOC**	**STO Manager**
Mary Miller	Glenn Harrison	Wayne Mantay
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–3203	(757) 864–3953
329–1543	558–3203	927–3953

IV.AV.2000.01—ROTORCRAFT ENHANCED SURVIVABILITY TECHNOLOGIES (REST). The focus of this program is to develop and demonstrate a 50 percent reduction in aircraft signatures (infrared/electro-optic/visual) that provides a 50 percent increase in aircraft survivability (active/passive) through advanced survivability countermeasure components.

In FY00, designed and developed advanced engine IR suppression concepts. By the end of FY01, demonstrate 75 percent reduction in engine exhaust IR signature with 25 percent reduction in component weight and cost (TRL 4). By the end of FY02, demonstrate 50 percent reduction in engine liner thermal insulation weight. By the end of FY03, demonstrate 50 percent reduction in visual/EO detection range through advanced camouflage and low-glint canopy materials (TRL 5).

Supports: AH–64, UH–60, RAH–66 upgrades, CH–47F and FTR developments; other service aircraft.

TSO	**TRADOC POC**	**STO Manager**
Mary Miller	Ted Hundley	Malcom Dinning
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–1465	(757) 878–5476
329–1543	558–1465	927–5476

IV.AV.2000.02—ROTORCRAFT OPEN SYSTEMS AVIONICS (ROSA). The focus of this STO is to select, develop, and evaluate the key components of an open systems mission avionics architecture (i.e., the embedded processing infrastructure) for dual applications to modern military and civilian rotorcraft; create a set of open-architectural specifications and standards leveraging market-driven COTS electronics products compliant with Joint Technical Architecture requirements; and promote endorsement of the specifications by the U.S. rotorcraft industry and the appropriate standards bodies.

In FY00, defined avionics architecture technical requirements, developed a technical reference architecture, and conducted laboratory evaluations of a 16 × 16 port fiber-channel high-speed computer interconnect network switch. By the end of FY01, design a COTS-based open avionics architecture, consistent with the defined specifications and standards, that increases plug-and-play by 70 percent; allows clock rates and memory to double every 18 months; and reduces platform network and component costs by 40 percent, unique module count by 50 percent, and LRU count by 66 percent. Evaluate an ultra-high-speed architecture (of at least 1 Gbps) that increases bus bandwidth by a factor of 2 to 20 and improves throughput by a factor of 10 to 25. Host and run display software in real time using Comanche and Apache software as test articles to evaluate COTS-based operating system portability. Investigate the effects on failure rates and reduce architecture size/weight/power consumption by 40 percent. Also by the end of FY01, transition draft specifications and standards for open-system architecture to follow on planned advanced development, integration, and flight test and demonstration (TRL 5).

TSO	**TRADOC POC**	**STO Manager**
Mary Miller	Ted Hundley	Dale Johnson
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–1465	(757) 878–0123
329–1543	558–1465	927–0123

IV.AV.2000.03—LOW-COST ACTIVE ROTOR (LCAR). This STO develops the high-risk 6.2 variable-geometry rotor on-blade control technologies to transition to the Army After Next 6.3 Active "No-Swashplate" Rotor Tech Demo.

By FY01, complete a critical assessment of load models for variable-geometry rotor applications and benchtest advanced actuator concept (TRL 3). By FY02, develop an improved load model for integrated controls. By FY03, develop an affordability analysis model and apply it to achieve a 30 percent reduction in rotor life cycle costs, define no-swashplate rotor geometries, and assess morphable rotor blade actuation for primary control. By FY04, design a wind-tunnel model that will demonstrate a 40 percent reduction in rotorcraft vibration and maximum rotor blade loading increases of 16 percent with a 20 percent range increase from control system weight savings (TRL 4). The wind tunnel model design transitions to follow-on fabrication and wind tunnel testing as outlined in the DoD Rotors Plan.

TSO	**TRADOC POC**	**STO Manager**
Mary Miller	Ted Hundley	Wayne Mantay
SAAL–TT	USAAVNC	AMRDEC
(703) 601–1543	(334) 255–1465	(757) 864–3953
329–1543	558–1465	927–3953

COMMAND, CONTROL, COMMUNICATIONS, AND COMPUTERS

IV.C4.1997.01—ANTENNAS FOR COMMUNICATIONS ACROSS THE SPECTRUM. The objective of this STO is to develop, leverage, and apply emerging antenna technology to reduce the number of antennas, reduce the visual signature (conformal), reduce the cosite and control problems, and increase efficiencies and radiation patterns in the ranges of 2 MHz to 2 GHz. A second goal is to provide on-the-move (OTM) SATCOM antenna capabilities in X and EHF bands. Seven different technologies will be explored to address different applications. For Joint Tactical Radio System (JTRS) applications, wideband technology (30–450 MHz) will be exploited. For air and ground vehicles, structurally embedded reconfigurable antenna technology (SERAT) and structure-tuned antenna techniques (225–450 MHz) will be used. SHF and EHF low-profile, self-steering, OTM antenna technology will be applied to the SATCOM applications. The initial thrust will be to address the broadband requirements for JTRS. Following this, the program will be expanded to pursue the remaining efforts concurrently.

Demonstrated a UHF conformal antenna (SERAT) on a Blackhawk in FY98 and on a selected ground platform in FY99. In FY99, fabricated and demonstrated a structured tuned VHF antenna on a ground vehicle. In FY00, demonstrated a wideband JTRS antenna and an X-band OTM self-steering SATCOM antenna capability. In FY01, demonstrate an OTM self-steering EHF SATCOM antenna capability (TRL 6).

For soldier antenna extension, an additional effort was being initiated in FY99 to address antenna solutions for the Dismounted Warrior. A highly efficient multiband radiation system contained in a physically small package will be capable of functioning while the soldier is standing or prone.

Completed analysis in FY99, and designed a prototype antenna system in FY00. In FY01, conduct a demonstration and use additional propagation measurements to refine the design (TRL 4).

For ferroelectric phased-array antenna (PAA) extension, the goal is to develop an OTM communications (X-band), PAA using ferroelectric materials for phase shifting. This approach has the potential to reduce the production costs for PAAs by 25–50 percent.

In FY99, completed an analysis and fabrication of a four-element subarray, resulting in a proposed design. In FY00, completed a breadboard of the subarray. In FY01, complete a prototype antenna and integrate it into a vehicle for demonstration with a Defense Satellite Communications System (DSCS) satellite (TRL 5). Performance will be compared using the current Juniper communications (electronically controlled) phased-array baseline.

Supports: JTRS, tactical airborne and ground vehicles, PM–Soldier , Direct Broadcast Satellite, DSCS, MILSTAR.

TSO	TRADOC POC	STO Manager
Rob Saunders	Tom Mims	Mark Seltzer
SAAL–TT	BCBL(G)	CERDEC/S&TCD
(703) 601–1546	(706) 791–2800	(732) 532–4925
329–1546	780–2800	992–4925

IV.C4.1997.02—PERSONAL COMMUNICATIONS SYSTEM FOR THE SOLDIER. The objective of this STO is to develop the next-generation LW radio technology by leveraging DARPA SUO Situational Awareness System (SAS) technology and adapting commercial technology (code division multiple access (CDMA)) and personal communications system (PCS) cellular waveform to support the needs of the dismounted soldier. A second goal is to satisfy the joint-service requirements for dismounted warfighter communications. The technical objectives will be executed in close cooperation with the DARPA SUO and GloMo programs. This technology offers significant advantages in multipath performance (MOUT application) and antijam/low-P_d protection. This effort will emphasize the elimination of fixed cellular infrastructure requirements on which commercial cellular land network systems are based. This STO will build on technical and operational experience acquired with spread-spectrum commercial wireless communications technology in various frequency bands acquired during Army activities in support of DARPA's Commercial Communications Technology Testbed and GloMo programs, DBC ATD, and the USMC Hunter Warrior and Sea Dragon exercises. This STO will develop peer-to-peer and multihop packet relaying protocols/technologies on portable computer host, leading to a demonstration of mobile communications for the dismounted soldier exploiting commercial chipsets and ASICs used in commercial systems.

In FY99, defined a host computer interface to enable rapid protocol development for implementation in portable (handheld) computer environments (e.g., personal digital assistants). In FY99 and FY00, demonstrated peer-to-peer and multihop packet relaying with DARPA SUO SAS and GloMo systems under the MOUT ACTD without reliance on cellular land network infrastructure. In FY00-FY01, develop information security technologies demonstrated under the CONDOR and MISSI/GloMo/SUO programs in the DARPA SUO Program and MOUT ACTD. In FY01, demonstrate a technology upgrade for the LW soldier platform (TRL 5). Benefits of spread-spectrum technology for tactical applications will be evaluated and demonstrated throughout the program.

Supports: MOUT, PM–Soldier.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	Chris Kearns	Francis Schurgot
SAAL–TT	DBBL	CERDEC/S&TCD
(703) 601–1546	(706) 545–6391	(732) 427–2793
329–1546	835–6391	987–2793

IV.C4.1998.01—ADVANCED BATTLEFIELD PROCESSING TECHNOLOGY. The objective of this effort is to develop an extensible, scalable, and adaptable software infrastructure to enhance C^2 decisionmaking. This research effort focuses on significantly improving the information access and operator focus of attention so that significant battlefield events are rapidly perceived and readily understood by the commanders and staff with minimal interaction.

In FY98, demonstrated software subsystems to enhance battlefield visualization fidelity. In FY99, demonstrated the display of 2D/3D terrain. In FY00, demonstrated software subsystems to integrate battlefield environment models with high-resolution terrain. By FY01, demonstrate software subsystems to enhance synchronized operations through focus of attention and seamless information access. By FY02, demonstrate software subsystems to evaluate hands-free multimodal human–computer interaction (natural language, eye-tracking, and gestures). This suite of tools will enhance BV capabilities of C^2 sys-

tems by improving scalability from the TOC to the platform level, and extensibility across the maneuver and Intel battlefield functional areas.

Supports: RBV ACTD, Log C^2 ATD, CERDEC.

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos	COL Michael Heredia	Larry Tokarcik
SAAL–TR	BCBL	ARL–IST
(703) 601–1524	(913) 864–8051	(301) 394–5614
329–1524	562–8051	290–5614

IV.C4.1999.01—COLLABORATION TECHNOLOGY FOR THE WARFIGHTER. The objective of this effort is to develop and prototype a set of collaborative planning tools that will focus on compressing the Observe–Orient–Decide–Act loop and provide commander and staff the capability to plan and execute at Objective Force speeds.

In FY99, procured hardware/software; acquired products from basic research, STOs, and COTS; designed military-unique Group Support System (GSS) capability; and evaluated electronic whiteboard and multimedia presentation software with BV architecture. In FY00, designed speech recognition/voice capability. In FY01, integrate GSS capability. In FY02, evaluate tools using information presentation metrics, refine tools from results of evaluation, and transition the toolset to RDEC for integration. The collaborative toolset provides (1) an improved capability for concurrent multiechelon mission planning and immediate plan dissemination by preserving commander's guidance and making it available at all levels, (2) tools for near-term use, (3) and a framework for the warfighter to provide feedback to technology. Collaboration technology for the warfighter lays a path to Objective Force technology by identifying the research and integration issues to be solved to attain execution-centric decisionmaking.

Supports: Battle Planning STO, Agile Commander ATD, CERDEC.

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos	MAJ Vance Chase	MAJ Rachel Borhauer
SAAL–TR	D&SABL	ARL–IS&T
(703) 601–1524	(580) 442–2936	(404) 894–3140
329–1524	639–2936	

IV.C4.1999.02—DISMOUNTED WARRIOR COMMAND, CONTROL, COMMUNICATIONS, COMPUTERS, AND INTELLIGENCE (C^4I) TECHNOLOGIES. This STO exploits significant military and commercial investments in wireless personal communications, mobile computing, and C^2 applications to ensure that the TSM–Soldier power, weight, and cost objectives are met, and that C^4I technologies and architectures are optimized for transition through the FXXI LW S&T and U.S. Army LW P^3I programs. This is being accomplished through technical collaboration with DARPA programs (e.g., GloMo, SUO), the AMC S&T initiatives identified in the SBCCOM Warrior Systems Modernization Strategy, advanced C^4I technologies and architecture designs emerging from the DARPA SUO SAS Program, commercial developers of consumer electronics and wireless communications products, and other ongoing CERDEC STOs.

In FY00, designed and developed technical demonstrations and field experiments with the combat developer. In FY01, complete system design architecture and provide early software prototyping. During FY02 and FY03, develop prototype hardware and software and support technical demonstrations. In FY04, complete prototype hardware and software development and system integration and testing, perform a final field experiment, and develop technical documentation (TRL 5).

Supports: PM–Soldier, JTRS.

TSO	TRADOC POC	STO Manager
Rob Saunders	Chris Kearns	Perry Hugo
SAAL–TT	DBBL	CERDEC/S&TCD
(703) 601–1546	(706) 545–6391	(732) 427–2295
329–1546	835–6391	987–2295

IV.C4.2000.01—DYNAMIC READDRESSING AND MANAGEMENT FOR ARMY 2010 (DRAMA). This STO investigates and develops solutions for the Army's dynamic network addressing and adaptive network management problems in the Warfighter Information Network–Tactical (WIN–T), Wideband Radio Network Testbed (WRNT), and Joint Tactical Radio System (JTRS) operational environment. Addressing problems are created by node initialization, node (host) mobility, and the requirement to reconstitute a network from a previously operational network that has been torn apart by battle damage. The addressing must also be supported through adaptive network management based on the static, preassigned addressing scheme of the commercial Internet and equivalent commercial architectures (i.e., plain old telephone service (POTS), Narrowband—Integrated Services Digital Network (N–ISDN), ATM), where address assignment and reconfiguration is done on a prepared basis or by the client request to a central controlling organization. This effort will leverage DARPA-related initiatives, specifically those in the emerging fields of active networks and mobile agents. Additionally, an intelligence systems-enabled, automatic network management capability will be investigated that will provide both centralized and decentralized network management and utilize rule-based and fuzzy set reasoning as well as artificial neural nets to provide self-management. It will also furnish network status back to centralized network management terminals and be capable of displaying the network at a glance, identifying problem areas, identifying how the now "smart" terminals are managing the network, and providing an override capability if required.

In FY01, initiate dynamic readdressing protocols and dynamic Management Information Base investigation. In FY02, develop details of the protocols and algorithms that may be active networks and mobile agent based to ensure proper operation. In FY03, prototype the protocols and algorithms and demonstrate them in a single-network environment. In FY04, enhance the algorithms/protocols to support TCP/IP over ATM and demonstrate network healing as a result of simple network anomalies. In FY05, conduct an experiment that integrates the results of the readdressing algorithms into the network and assess the ability of the net management tools to interpret and react. Both functional and performance algorithms will be used as metrics in the interconnection of dynamic addressing algorithms and net management/monitoring tools.

Supports: Objective Force; Force XXI Battle Command and Brigade and Below.

TSO	TRADOC POC	STO Manager
Rob Saunders	Tom Mims	Larry Levine
SAAL–TT	BCBL(G)	CERDEC/S&TCD
(703) 601–1546	(706) 791–2800	(732) 427–2334
329–1546	780–2800	987–2334

IV.C4.2001.01—FREE-SPACE OPTICAL COMMUNICATION SYSTEM. This STO develops covert, short-range communications systems for the lower echelon maneuver and armor force, to support high-capacity multimedia information exchange on Force XXI and Objective Force battlefields. Laser communications are being used in the development of hardware appropriate for horizontal technology integration into new ground and airborne fighting platforms, with operational goals of covertness, high capacity (several Mbps), and operational ranges of up to several kilometers. This program leverages the transition effort of DARPA's Stabilized Agile Beams (STAB) Program (FY00–05). Technology affordability drivers include low-cost lasers, MEMS devices, and improved pointing and tracking mechanisms. The final product will be a full-duplex, on-the-move laser communications system in the initial range of 3 km. Low cost and size reduction will be emphasized in this development.

In FY01, develop an overall system and network architecture and first-order evaluation of adaptive optics communications subsystem concept over a 1-mile airpath (TRL 3). In FY02, complete design of subsystems (transmitter laser, tracking hardware, downconversion unit, etc.) (TRL 3/4). In FY03, conduct laboratory demonstration emphasizing subsystem developments (TRL 4). In FY04, perform an integration test of the entire system and a limited laboratory analysis and test implemented in a controlled environment (TRL 4/5). In FY05, demonstrate a network-oriented laser communication system on a surrogate FCS platform (TRL 5).

Supports: PM–WIN–T, Objective Force, FCS, PEO–C^{3}S, PEO–IEW&S.

TSO	TRADOC POC	STO Manager
Rob Saunders	Tom Mims	Neil Vallestero
SAAL–TT	BCBL(G)	CERDEC/S&TCD
(703) 601–1546	(706) 791–2800	(732) 427–4277
329–1546	780–2800	987–4277

ELECTRONIC WARFARE

IV.EW.1998.01—LOW-COST, ELECTRO-OPTIC/INFRARED COUNTERMEASURES (EOCM/IRCM). This STO develops active/passive devices to protect aircraft and ground vehicles with conventional and suppressed signatures from EO and IR guided threats. Countermeasures to IR missiles is the number one DoD EW priority. IR imaging missiles plus multispectral IR, EO, and RF seekers that are being fielded must be countered. Technology development will focus on key components, such as sources, optics, pointing and tracking devices, advanced jamming techniques against passive homing, command to LOS, beamrider missiles, and missile detection algorithms. Emphasis will be on horizontal technology integration of EW architecture infused with low-cost and adapted NDI technologies for air and ground vehicle protection.

In FY00, demonstrated advanced onboard laser-based jamming techniques used in conjunction with offboard devices against advanced and imaging EO and IR SAM and ATGM threats. By FY01, demonstrate jamming techniques versus advanced laser beamrider threats. By FY02, develop nonmechanical multiband beamsteering for laser-based jamming sources, and demonstrate jamming effects against advanced multiband IR and EO missiles capable of attacking suppressed signature air and ground platforms (TRL 5). By FY03, demonstrate a jamming source capable of defeating multispectral IR, EO, and UV missile seekers (TRL 6).

Supports: PEO–IEW&S, AMBL, MBSBL, D&SABL, BCBL.

TSO	TRADOC POC	STO Manager
Rob Saunders	Ted Hundley	Allan Chan
SAAL–TT	USAAVNC	CERDEC/I2WD
(703) 601–1546	(334) 255–1465	(732) 427–4019
329–1546	558–1465	987–4019

IV.EW.1998.02—ADVANCED ELECTRONIC WARFARE SENSORS. This program will develop HTI-capable multispectral missile, laser, and radar warning sensors with precision angle of arrival, primarily to control and direct countermeasures, but with added capability for enhanced situational awareness, target cueing, and CID assist. The multispectral sensor in a single head will reduce weight, maintenance, and spare logistics. Emphasis will be on HTI of EW sensors infused with low-cost and adapted NDI technologies for air and ground vehicle threat detection. The developed sensor technology will be P^3I for the AN/ALQ–211 and AN/ALQ–212, and will provide expanded capability against multispectral and updated RF, IR, EO, and laser air defense and ground threat weapons.

In FY99, initiated development of multi-octave antennas for multispectral SAMs, top-attack munitions, and antiaircraft mines. In FY00, conducted field testing of antennas and ECM, transitioned to Integrated Situation Awareness and Targeting, and initiated development of common air/ground vehicle sensor and countermeasure modules (TRL 3). By FY01, continue development of common air/ground sensors/countermeasures against phased-array and ultra-wide-bandwidth (UWB) radars with advanced ECCM modes. By FY02, field-test common air/ground sensors/countermeasures against phased-array and UWB radars and transition to the CAGES demonstration program. In FY03, conduct tests of countermeasures to multispectral SAMs, antiair mines, UWB radars, and advanced multispectral top-attack munitions (TRL 5).

Supports: PM–AES, DBBL, MBSBL, D&SABL, BCBL, EELSBL.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	Ted Hundley	Ray Irwin
SAAL–TT	USAAVNC	CERDEC/I2WD
(703) 601–1546	(334) 255–1465	(732) 427–4589
329–1546	558–1465	987–4589

IV.EW.2000.01—ADVANCED RADAR DECEPTION AND COUNTERMEASURES. This program develops new EW technology that will deceive an enemy's radar-based sensors and neutralize their ability to locate, target, and guide weapons against early-entry forces and the Objective Force. Tactical radars will be deceived, new hard-to-detect and hard-to-jam spread-spectrum air defense radars will be neutralized, and smart top-attack munitions using RF sensors will be jammed. HTI principles that leverage DARPA and tri-service advances in component technology will be used to develop a new generation of common deception and countermeasures modules that maximize hardware and software commonality across aircraft, ground vehicles, and soldier systems. These forms of electronic deception will be critical to the survivability of the highly armored strike forces envisioned for the Objective Force. Technology in these modules will support plug-and-play "modernizing through spares" and major system upgrades. Benefits include a wideband EW modulator, algorithms and antennas that will provide enhanced emitter location and identification, deception and countermeasures against enemy sensors and weapon systems, and reductions in weight, life cycle, cost, and maintenance

In FY00, conducted simulations with battle labs and schools, developed and lab-tested low-cost multi-functional air and ground vehicle deception and countermeasure modulators and algorithms based on DARPA/tri-service ultra-wideband receivers, and began technical tests of integrated COMINT/ELINT processors and receivers. In FY01, conduct field deception testing against targeting and air defense radars. In FY02, complete simulation and emitter ID and location enhancements, field-test against frequency-hopping air defense radars and top-attack munitions, and evaluate enhancements in detection and location given COMINT/ELINT integration. In FY03, develop modulator hardware and algorithms and test versus new radar and fuze threats (TRL 5). In FY04, demonstrate capability for one-on-many deception and jamming, produce final report, and transition to CAGES technology demonstration, PM–ASE ALQ–211, and PM–FF Shortstop. Achieve 70 percent reduction of shots and launches by monopulse and phased-array radars and missile seekers. Complete receive and deceive search, acquisition, and imaging radars (metric classified). Jam top-attack munitions, new Category 2 and 3 artillery and AAA fuzes, prefunction 98 percent at 200 percent lethal range, 200 percent jam range increase for 90 percent of all rounds (TRL 6).

Supports: ISAT ATD, PEO–AVN, PEO–IEW&S, AMBL, DMBL, MBSL, D&SABL, BCBL.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	Ted Hundley	Gerry Melendez
SAAL–TT	USAAVNC	CERDEC/I2WD
(703) 601–1546	(334) 255–1465	(732) 427–2900
329–1546	558–1465	987–2900

IV.EW.2001.01—COMPACT LASER SOURCES FOR INFRARED COUNTERMEASURES (IRCM). This program provides enhanced survivability against thermal weapons by providing tactical IRCM to jam present and future threats to the FCS and to rotary-wing (and other) aircraft from air- and ground-launched missiles with IR seekers. A secondary benefit that can be derived from this effort will be an enhanced ability for environmental monitoring in the IR wavelength regions.

By the end of FY01, demonstrate high-efficiency operation of semiconductor IR lasers (TRL 3). By the end of FY02, demonstrate two-wavelength (bands II and IV) semiconductor IR lasers that are thermoelectrically cooled with significant advantages in weight, size, power consumption, and output power (TRL 4). By the end of FY03, demonstrate three-wavelength (bands I, II, and IV) semiconductor lasers for IRCM applications with a 50 percent reduction in size, weight, and power consumption over current IRCM systems (TRL 5).

Supports: Objective Force, FCS.

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos	Ted Hundley	J. Pamulapati
SAAL–TR	USAAVNC	ARL–SEDD
(703) 601–1524	(334) 255–1465	(301) 394–1475
329–1524	558–1465	290–1475

GROUND COMBAT AND TACTICAL SYSTEMS

IV.GC.1997.01—ARMAMENT DECISION AIDS. This STO leverages emerging artificial intelligence and information processing technologies to develop and demonstrate a suite of reusable and adaptable weapon crew decision aid components, algorithms, and supporting software process/repository for advanced self-propelled howitzer and embedded armament system applications.

In FY98, completed object-oriented analysis and functional specification, implemented preliminary set of software components for evaluation by D&SABL, and demonstrated preliminary voice/natural language interface capability. In FY99, developed joint tactical architecture (JTA)-compliant decision aids architecture and integrated baseline software components with JTA-compliant operating environment and map service application program interface. In FY00, demonstrated software components that reason based on digital terrain data, with a 60 percent reduction in time required to respond, emplace, fire, and conduct survivability moves while operating with a maneuver force, as compared with current methods. In FY01, demonstrate an expanded suite of reusable/adaptable armament decision aid components and supporting software process/repository technology to provide significant reduction in workload, mission response time, and software cost. Demonstrate robust voice/natural language operator interface capability functional in a high-noise (120 dB) vehicle environment (TRL 5).

Supports: Crusader, Paladin P^3I, MMBL.

TSO	TRADOC POC	STO Manager
John Appel	Susan I. Walker	Dr. Norman Coleman
SAAL–TT	FA School	ARDEC
(703) 601–1537	(405) 442–6309	(973) 724–6279
329–1537	639–6309	880–6279

IV.GC.1997.02—LASER PROTECTION FOR GROUND VEHICLE VISION SYSTEMS. The goal of this program is to build and test a demonstrator of a new, retrofittable, wide-angle optical viewing system incorporating advanced laser protection materials. These new optical systems could replace the current vision blocks found in combat vehicles, allowing the soldier to view the battlefield while protected from eye-damaging laser energy, including frequency agile laser weapons.

In FY98, completed limiting material synthesis. In FY99, demonstrated optical design that can incorporate limiting or dispersive materials. In FY00, finished limiter module fabrication. In FY01, build and test brassboard of the new optical design incorporating advanced laser protection materials (TRL 6).

Supports: Crusader, FCS, Legacy systems.

TSO	TRADOC POC	STO Manager
John Appel	Winkenhofer/Smith	Doug Templeton
SAAL–TT	Armor Center/Infantry Center	TARDEC
(703) 601–1537	(502) 624–8064/(706) 545–1915	(810) 574–5325
329–1537	464–8064/835–1915	786–5325

IV.GC.1998.01—COMBAT VEHICLE CONCEPTS AND ANALYSIS. This STO develops vehicle concepts for the Army's next generation of combat and combat support vehicles. The goals are to refine user requirements through the integrated concept team (ICT) process, develop the vehicle alternatives for the formal analysis of alternatives (AOA) for Milestone B decisions, and provide technologists with vehicle-based technology and component guidance for weight, volume, and electrical interfaces.

In FY98, developed FSCS vehicle concepts with 25 percent increased crew efficiency, 20 percent reduced vehicle silhouette, 10 percent increase in mobility, 20 percent increase in vehicle and crew survivability, and 500 percent increase in target detection rate. In FY99, determined optimal FCS lethality option that will increase range by 50 percent with a P_k/second of 1.0 and an 80 percent increased loss exchange ratio and refine FSCS concepts; and developed Future Infantry Vehicle (FIV) concepts that will increase capacity to carry a squad (from seven to nine soldiers, with full LW gear), decrease vehicle crew size by 33 percent, increase survivability by 33 percent, and improve mobility by 50 percent. In FY00, transferred FIV designs and FCS concepts and analyses to the FCS concepts and develop a series of FCS-based concepts for multiple mission roles, and perform performance and affordability analysis. By FY01, develop additional FCS variant concepts with 33 percent reduced gross vehicle weight and 25 percent reduced crew workload, explore robotic vehicle concept variants, and complete Abrams upgrade concepts. By FY02, establish and address emerging vehicle requirements and the needs of future ICTs for the Objective Force, complete FCS concepts and analysis and transition data to industry teams, and complete Bradley upgrade concepts.

Supports: FCS, Abrams, Bradley, integrated concept teams, AOAs and TRADOC for development of mission need statements and operational requirements documents.

TSO	TRADOC POC	STO Manager
John Appel	Winkenhofer/Smith	Roger Halle
SAAL–TT	Armor Center/Infantry Center	TARDEC
(703) 601–1537	(502) 624–8064/(706) 545–1915	(810) 574–5287
329–1537	464–8064/835–1915	786–5287

IV.GC.1999.01—COMBAT HYBRID POWER SYSTEMS (CHPS). DARPA transitioned their Combat Hybrid Power System (CHPS) program to the Army in FY00. The key benefit of this transition was the transfer of a fully operational systems integration laboratory (SIL) specifically designed to evaluate hybrid electric power systems for potential application to future manned and unmanned ground combat vehicle platforms. The SIL has the capability to evaluate electric propulsion motors, flywheel or battery energy storage capabilities, advanced engines, advanced Silicon Carbide motor controller/inverter, pulsed forming network for directed-energy weapons (DEWs) and EM armor. The SIL contains emulated components to represent the power load requirements of DEW, EM armor, and ETC gun to enable the Army to gather critical data and design criteria for propulsion system sizing and cooling requirements and to assess component performance and durability.

By FY01, test the power architecture of the 15-ton propulsion system designed by DARPA to use as a baseline (TRL 5). By FY02, demonstrate a power system capable of meeting the power requirements for a notional 20-ton platform that would be compatible with the FCS requirements (TRL 5). By FY03, deliver propulsion system design criteria to the FCS contractors.

Supports: FCS.

TSO	TRADOC POC	STO Manager
John Appel	COL Hobbs	Gene Baker
SAAL–TT	DCD, USAICS/S	TARDEC
(703) 601–1537	(304) 545–1316	(810) 574–6390
329–1537	835–1316	786–6390

IV.GC.2000.01—CONCEPTS FOR 21ST CENTURY TRUCK-BASED TACTICAL VEHICLES. This program demonstrates—through virtual prototyping, modeling, and simulation—the feasibility and operational potential of advanced commercial and military technologies with application to new and existing tactical vehicles, and describes the capabilities of potential future tactical vehicles. The goal is to show that onboard training and battle rehearsal can be increased 100 percent and mobility can be increased 50 percent. The effort includes technology assessments, vehicle-level concept designs, system integration studies, tradeoff studies, and performance and supportability analyses. This STO will refine user requirements through the ICT process, provide technologists vehicle-level and system guidance, and develop the vehicle alternatives. Concept designs will leverage and incorporate both military and commercial technologies, including dual use National Automotive Center (NAC) technologies and simulation-based acquisition activities. These concepts will in turn direct NAC programs with exit criteria and weight and space claim allocations. Specific NAC programs that will be integrated include 21st Century Truck technologies (advanced propulsion, vehicle intelligence, advanced materials), high-output diesel engines, metal-matrix composites, electromechanical suspensions, and electronically controlled active braking systems.

In FY00, evaluated commercial and military technologies to determine capabilities and deficiencies, and developed program plans. In FY01, develop virtual prototypes (concept level) of future heavy tactical vehicle configurations that will improve mobility, survivability, transportability, and supportability. By FY02, conduct mobility, survivability, and transportability performance analyses of heavy tactical vehicle concepts, and develop virtual prototypes of future medium tactical vehicle configurations. By FY03, conduct tradeoff analyses of heavy tactical vehicle concepts, conduct performance analyses of medium tactical vehicle, and develop virtual prototypes of future light tactical vehicle configurations.

Supports: Replacements/upgrades to PLS, HEMTT, other medium/heavy/light vehicles.

TSO	TRADOC POC	STO Manager
John Appel	COL Kubiszewski	Nance Halle
SAAL–TT	Transportation School/DCD	TARDEC
(703) 601–1537	(804) 739–0267	(810) 574–8646
329–1537	687–0267	786–8646

IV.GC.2000.02—BALLISTIC PROTECTION FOR FUTURE COMBAT SYSTEMS. This program develops and tests advanced armor systems that address the ground platform needs of the FCS for protected firepower and survivable mounted infantry. It will build on lightweight armor systems developed under the Future Light Vehicle Ballistic Protection Technology STO and Integrated Armors/Structures for Lightweight Vehicles, using advanced materials (lightweight metals, ceramics, ceramic laminates, composites, and energetic materials), advance structure technologies, and advanced armor concepts. This STO will validate the ballistic performance, structural capability, and durability; and assess fabricability and affordability.

By FY01, assess protection needs for FCS for frontal, rear, top, and bottom vehicle zones; and demonstrate advanced armor technologies for each zone. By FY02, demonstrate second-generation armor configurations, and apply modeling and simulation tools. By FY03, demonstrate optimized armor configurations, including frontal armor at 80 lb/ft^2 to defeat medium-caliber automatic cannon threats, shaped-charge threats, and residual threat debris from large-caliber KE intercepted by an APS; and armor to defeat heavy machine gun threats at 20 lb/ft^2. In FY04, conduct tests to verify final designs. Achieve TRL 5 in FY03 and TRL 6 in FY04; the goal is TRL 7 by FY06.

Supports: FCS, IAV.

TSO	TRADOC POC	STO Manager
John Appel	COL Henry Hughes	James L. Thompson
SAAL–TT	Armor Center, DFD	TACOM–TARDEC
(703) 601–1537	(502) 624–5050	(810) 574–5780
329–1537	464–5050	786–5780

IV.GC.2001.03—SEMIAUTONOMOUS ROBOTICS FOR FUTURE COMBAT SYSTEMS. This STO will develop autonomous mobility technology critical for future Army Objective Force systems, including unmanned elements of FCS and crew aids for manned systems. The principal focus is on robotic elements that maneuver in high-hazard environments forward of manned systems. This program will combine robotic functionality with human capabilities to provide flexible, semiautonomous control modes for FCS elements. It will support and complement the joint TARDEC/ARL Robotic Follower ATD. A key element of this STO is the formation of a Robotics Research Alliance—a consortium of industrial and academic institutions working collaboratively with ARL and Army RDECs to advance robotics technology. Technical efforts will be focused on the continuous advancement of perception for autonomous ground mobility, intelligent vehicle control and behavior, and human supervision of unmanned ground systems, including specialized sensor and network developments required to achieve robust semiautonomous performance.

In FY01, develop and integrate multisensor perception technology required to implement baseline leader-follower operation; demonstrate technology for cross-country semiautonomous mobility at speeds of up to 20 mph, equivalent to 50 percent of the speed of a manned HMMWV in a similar environment; and establish the Robotics Research Alliance (TRL 4). In FY02, develop technology required for tactical behaviors common to multiple military missions, including autonomously seeking cover or concealment in terrain characterized by rolling meadows and light forestation (TRL 4). In FY03, develop and implement baseline hardcoded tactical behaviors for "preceder" missions, demonstrating use of terrain to mask movement and minimize vulnerability over multi-kilometer routes—with operator interven-

tion only for exceptional situations (TRL 5). In FY04, demonstrate semiautonomous cross-country mobility at speeds of up to 35 mph (day)/20 mph (night) on an FCS "companion" scale vehicle; and demonstrate baseline cooperative preceder tactical behaviors, including two vehicles providing mutual support cover during a multi-kilometer route of march (TRL 5). FY FY05, develop and demonstrate baseline adaptive tactical behaviors employing learning algorithms and robust mobility reducing the frequency and duration of operator intervention by 75 percent over FY03 levels (TRL 5).

Supports: FCS, joint service UGV programs, manned combat, tactical and support vehicle fleets.

TSO
Cathy Kominos
SAAL–TR
(703) 601–1524
329–1524

TRADOC POC
COL Joseph O. Rodriguez, Jr.
HQ, TRADOC
(757) 788–2217
680–2217

STO Manager
Mr. Charles Shoemaker
Army Research Laboratory
(410) 278–8810
298–8810

WEAPONS

IV.WP.1998.01—FLEXIBLE SUSTAINER FOR MULTIMISSION WEAPONS. This program demonstrates two approaches to developing a flexible sustainer for multimission weapons: (1) a low-thrust, controllable, bipropellant gel propulsion system, and (2) a pintle-controlled solid-propulsion system—both tightly integrated with the weapon system guidance and sensor to achieve dramatic gains in system performance. Each approach depends on determination of the optimum velocity required for range and target.

In FY99, demonstrated propulsion system performance in workhorse hardware, and develop advanced propellant. In FY00, downselected to a single approach, completed characterization of advanced propellant, and finalized design of flightweight component hardware. By FY01, complete flightweight component development and demonstrate high performance in a sustain engine (TRL 5). This flexible sustain technology will provide short time-to-target for close range, a doubling of the maximum range within the existing missile package, and high engagement velocities for improving terminal performance, particularly at the long ranges.

Supports: Mod Hellfire/CM, NetFires, FCS.

TSO	TRADOC POC	STO Manager
Mary Miller	Ted Hundley	Jerrold Arszman
SAAL–TT	USAAVNC	AMCOM AMRDEC
(703) 601–1543	(334) 255–1465	(256) 876–1288
329–1543	558–1465	746–1288

IV.WP.1998.02—TARGET DESTRUCT. This STO consists of two independent objectives and approaches for completion by the end of FY01. The first objective is to demonstrate, via modeling and both surrogate and actual threat target testing, the most promising advanced cannon and medium-caliber launched novel penetrators and warheads at ordnance and "superordnance" velocities and at extended range with up to 75 percent increase in lethality over the currently fielded equivalent caliber of ammunitions. The second objective is to demonstrate missile novel penetrators and warheads with 25 percent more lethality than conventional missile long-rod penetrators of equal weight, such as those used in CKEM. The STO results will lead to a more efficient defeat of threat target arrays for FCS, Abrams tank, and the Bradley fighting vehicle. For the first objective, lethal mechanisms considered include a variety of novel penetrators (including hypervelocity type) and novel warheads.

In FY98, developed novel penetrator warhead concepts capable of defeating threat target arrays (frontal top attack and Counteractive Protection System) associated with the FCS, defined Abrams tanks, completed simulation to determine the best technical approaches, and initiated fabrication of demonstration hardware. In FY99, initiated demonstrations of novel penetrator defeat FCS and Abrams threat targets, and completed novel penetrator concept design and selection of the best technical approaches for defeat of the Bradley and FCS threat target arrays. For the second objective, identified missile novel penetrators/warheads for enhanced lethality with reduced mass hypervelocity missiles. In FY00, completed demonstrations of heavy Abrams threat target defeat, and demonstrated novel penetrator defeat of heavy and light armored threat. In FY01, complete demonstrations of ordnance-launched novel penetrators and warheads against FCS targets and light-armored targets, conduct overall assessment of all

lethal mechanisms against future target arrays, and transfer the novel penetrator/warhead design to ARDEC, AMRDEC, LOSAT ACTD, and PM–TMAS.

Supports: Abrams tank, FCS, Bradley, AAAV, USAARMC, USAIS, USMC, ADKEM, LOSAT P^3I, CKEM.

TSO	**TRADOC POC**	**STO Manager**
John Appel	A. Winkenhofer	Anthony Sebasto
SAAL–TT	USAARMC	ARDEC
(703) 601–1537	(502) 624–8064	(973) 724–67004
329–1537	464–8064	880–7004

IV.WP.1998.03—AUTOMATIC TARGET RECOGNITION (ATR) FOR WEAPONS. DoD is looking to extend the range of conventional weapon systems through various technology approaches in order to facilitate a more favorable loss-exchange ratio on the battlefield. This STO will provide for effective weapon engagement against a widely dispersed threat within the context of the digital battlefield, and demonstrate extended range capabilities for lock-on after launch (LOAL), which will play a crucial role in future soldier/weapon platform survivability. ATR has the potential to provide the soldier with a weapon that has true LOAL fire-and-forget capability at extended ranges with the added benefits of reacquisition of targets after loss of lock, friendly avoidance, and optimum aimpoint selection for increased warhead effectiveness. This effort includes tri-service and industry assessments to determine the optimum approach for the Army.

In FY98, defined concept approach and collected data on various sensors under consideration. In FY99, exchanged and assessed Army, Air Force, and Navy approaches; and developed additional hardware and algorithms as required. In FY00, completed tower test and captive carry demonstrations of hardware/algorithms in realistic battlefield environments to include smoke and countermeasures (TRL 5). By FY01, use collected data in flight simulations and performance assessments for applicability to relevant weapon systems (TRL 6).

Supports: Modernized Hellfire/Common Missile; Brilliant Antitank (BAT) P^3I; UAV; extended range fire-and-forget, which demands LOAL; UGV; Avenger; Javelin.

TSO	**TRADOC POC**	**STO Manager**
Mary Miller	Warren Morimoto	Richard Sims
SAAL–TT	DCD, USAIC	AMCOM AMRDEC
(703) 601–1543	(706) 545–4268	(256) 876–1648
329–1543	835–4268	746–1648

IV.WP.1998.04—ADVANCED SENSORS FOR SMART MUNITIONS. This STO will demonstrate the application of a common aperture LADAR/IR transducer to enhance the current smart submunition sense and destroy armor (SADARM) sensor suite for use in gun launch environments. The sensor suite will improve countermeasure performance and provide target classification capability with specific performance goals, including $P_d > 0.90$, probability of classification (P_c) > 0.75, and 20X increase in footprint

compared with basic SADARM. The enhanced sensor suite performance will greatly reduce cost per kill for basic SADARM.

In FY98, conducted analysis of SADARM Block II sensor requirements in extended-range 155-mm round and MSTAR, and fabricated LADAR/IR prototype hardware for preliminary sensor suite evaluation. In FY99, fabricated test hardware for sensor CFT data gathering and g-hardening experiments; and performed CFT data gathering. In FY00, conducted system tradeoff studies on alternate Block II sensor designs, performed sensor suite packaging analyses, finalized sensor detailed design, and began fabrication of sensor hardware. By FY01, conduct tactical sensor CFT and sensor components g-hardening testing.

Supports: Sensor fuze munitions.

TSO	**TRADOC POC**	**STO Manager**
John Appel	MAJ Steve Walker	Anthony Pezzano
SAAL–TT	Armor Center, DFD	ARDEC
(703) 601–1537	(502) 624–8802	(201) 724–4829
329–1537	464–8802	880–4829

IV.WP.1998.05—120-MM EXTENDED-RANGE MORTAR CARTRIDGE. This STO develops an extended-range dual-purpose improved conventional munition mortar cartridge having 50 percent greater range and 80 percent greater effectiveness than the current M934/120-mm mortar system. Range extension is provided by a high-performance, lightweight composite rocket motor.

In FY98, established a baseline design configuration, completed interior and exterior ballistic analyses, and completed design of heavyweight test rocket motor and test fixtures. In FY99, fabricated lightweight composite rocket motor test hardware/test fixtures and initiated interior ballistic testing. In FY00, completed rocket motor static testing and updated interior and exterior ballistic models. By FY01, conduct a full-up flight test demonstration (TRL 4).

Supports: Family of all 120-mm mortar munitions, DBBL.

TSO	**TRADOC POC**	**STO Manager**
John Appel	Dave Hancock	Frank Brody
SAAL–TT	Infantry School	ARDEC
(703) 601–1537	(706) 545–4918	(201) 724–3728
329–1537	835–4918	880–3728

IV.WP.1999.01—COMPACT KINETIC-ENERGY MISSILE (CKEM) TECHNOLOGY. This program will develop and demonstrate advanced hypervelocity missile technology necessary for the next-generation KE weapon applicable to the Future Combat Systems. CKEM will demonstrate enhanced system lethality with a 4-foot/50-pound hypervelocity KE missile. Miniature guidance inertial measurement unit (IMU) technology will demonstrate high-g missile launch, independent of launcher attitude, and provide pre-

cision kill at target impact ranges of 0.40–5 km. The program will develop, mature, and demonstrate advanced components and subsystem technologies in a missile system configuration to achieve next-generation, system-level performance,

In FY00–01, demonstrate a 25 percent increase in missile lethality with novel penetrators and damage mechanisms other than penetration (TRL 4/5). In FY00, awarded industry/government cooperative programs for system concept studies and critical component development. By FY01, conduct government/industry operation environment component demonstrations for next-generation technology in advanced propulsion, enhanced lethality, miniaturized high-g guidance and control components, fully navigational IMUs, and other critical technologies as identified in detailed design concept studies. By FY02, demonstrate critical technologies applicable to FCS weapon system application in battlefield operational environments and validate through use of battlefield SMART (TRL 5/6).

TSO	TRADOC POC	STO Manager
Mary Miller	COL Dennis Szydlowski	George Snyder
SAAL–TT	MMBL	AMCOM AMRDEC
(703) 601–1543	(502) 624–7809	(256) 876–3048
329–1543	464–7809	746–3048

IV.WP.1999.02—POINT-HIT MULTIPLE LAUNCH ROCKET SYSTEM (MLRS). This STO designs, develops, and tests a cost-effective, jamming-resistant, precision guidance package for application to the M270 family of munitions (ATACMS/MLRS).

In FY99, evaluated methods for computing and transmitting the GPS correction to the launcher, GPS Selective Availability Antispoofing Module (SAASM) receiver candidates, antijam filters, and antenna designs; initiated 6-DOF analysis; and completed electronic guidance unit detailed design. In FY00, demonstrated testing of the method for computing and transmitting the correction as part of the ATACMS penetrator demonstration, accomplished testing of the GPS SAASM receivers and antennas, and assembled the guidance electronic unit and antennas. By the end of FY01, demonstrate the guidance package in an HITL and jamming environment and transition the results to the Guided MLRS SDD (TRL 6).

Supports: PEO–TM, MLRS.

TSO	TRADOC POC	STO Manager
Mary Miller	COL Kermit Edney Jr.	Alan Gamble
SAAL–TT	Combat Developments	AMCOM AMRDEC
(703) 601–1543	(405) 442–6980	(256) 876–2511
329–1543	639–6980	746–2511

IV.WP.2000.01—LOITERING ATTACK MUNITION—AVIATION (LAM–A). This STO demonstrates, through flight simulations and component developments, technologies for long-range (>50 km) weapon systems for airborne forces that will provide enhanced sensor-shooter connectivity, continuous in-flight autonomous feedback of target coordinates to local field commanders, minimized timeline for placing weapons on target, and battlefield damage assessment with last images before impact. It also demonstrates ATR and man-in-the-loop target acquisition and engagement concepts. This effort will also provide a rail interface and boost motor design capable of achieving stable helicopter rail launch in the presence of rotor downwash.

In FY00, performed assessments and simulations to determine the objective datalink requirements and approach; identified and tested turbojet maturation issues, and performed simulations to determine motor performance requirements; and initiated detailed designs of two methods to adapt developmental LAM for rotary-wing applications. By the end of FY01, complete a design of the flexible datalink, quantify improvements to the turbojets, select the most economical technology and approach for helicopter-launched LAM, and complete the fabrication of bench test prototype hardware. By the end of FY02, complete and test a breadboard datalink demonstrating key system capabilities, and test a rail launch system (TRL 5/6). Additional funds in this STO will be used to accelerate development of the LAM- A by the NetFires contractors.

Supports: Beyond line-of-sight networked fires for Army aviation, Hunter/Standoff-Killer ACTD, Mounted Maneuver Battlespace Lab, USMC expeditionary forces, USN submarine littoral warfare missile.

TSO	DARPA POC	STO Manager
Mary Miller	LTC Brad Tousley	John Meadows/G. Jimmerson
SAAL–TT	PM, NetFires	AMCOM AMRDEC
(703) 601–1543	(703) 696-2355	(256) 876–3708/3015
329–1543	426–2355	746–3708/3015

IV.WP.2000.02—MICROELECTROMECHANICAL SYSTEMS (MEMS)-BASED ANGULAR RATE SENSORS (MBARS). MBARS, a joint AMCOM AMRDEC/ARL WMRD/DARPA effort, demonstrates (1) a militarized, miniature, inexpensive, dual-axis, rate-grade, MEMS-based angular rate sensor (ARS) on a single substrate for pitch/yaw airframe stabilization; and (2) a roll rate sensor (RRS) for small tactical missiles.

In FY00, flight-tested a 200-deg/hr single-axis MEMS-based ARS for airframe stabilization, and assessed technology concepts/designs for RRS to support the needs of the Advanced Precision Kill Weapon System (APKWS). By the end of FY01, combine two single-axis MEMS-based ARSs to form a dual-axis sensor, and ground-test it over military environments; and develop a prototype MEMS-based RRS that meets the APKWS inertial instruments design requirements. By the end of FY02, test a dual-axis MEMS-based ARS that incorporates technology developed under DARPA programs. Both the dual-axis MEMS-based ARS and the single-axis RRS will be tested in the laboratory and in a full-up HWIL environment using the APKWS simulation. In addition, affordable MEMS-based dual-axis and single-axis ARSs will be demonstrated in flight tests on the 2.75 Hydra–70. By the end of FY03, insert the technology into the APKWS program, which will be available for transition to FCS and industry (TRL 7).

Supports: APKWS, MHF/CM, NetFires.

TSO	**TRADOC POC**	**STO Manager**
Mary Miller	COL Kim Summers	Dr. Paul B. Ruffin
SAAL–TT	AMBL	AMCOM AMRDEC
(703) 601–1543	(334) 255–3022	(256) 876–1717
329–1543	558–3022	746–1717

IV.WP.2000.03—**DEEP THROTTLING BOOSTER.** This program demonstrates thrust modulation over wider ranges (high turndown ratios) than those achievable with current technology. It extends the capabilities of controllable thrust technology to further increase range, enhance the end game, and provide multi-mission capability for a family of close combat weapons. Deep throttling booster technology could also be extended to close- to medium-range air defense weapons that use higher performing smoky propellants. Integrating these enhanced capabilities with advances in guidance and sensor technologies can greatly improve weapon system performance.

By the end of FY01, develop system-level concepts, select two competing propulsion options for brassboard evaluation, and begin design of component hardware. By the end of FY02, complete design of, fabricate, and demonstrate components in brassboard hardware. By the end of FY03, design, fabricate, and static-test integrated hardware in a system configuration. By the end of FY04, complete testing and update design concepts (TRL 5).

Supports: MHF/CM.

TSO	**TRADOC POC**	**STO Manager**
Mary Miller	COL Kim Summers	Michael W. Morrison
SAAL–TT	AMBL	AMCOM AMRDEC
(703) 601–1543	(334) 255–3022	(256) 876–1289
329–1543	558–3022	746–1289

IV.WP.2000.04—**AGILE TARGET EFFECT(S) SYSTEMS FOR THE BATTLEFIELD.** This program focuses on the development of a brassboard advanced Multimission Weapon System (MMWS), which is capable of agile target effects, is tunable against a variety of materiel and personnel targets from 0 to 2 km, and uses one or more combinations of technologies. Three candidate technologies will be investigated initially for their interactive operability and effectiveness: (1) a pulsed impulsive laser generator, with firepower effects greater than a .50-cal machine gun, for "lethal" antipersonnel, missile, UAV, and sensor applications; (2) a flat-panel solid-state or tube-based, multimegawatt microwave generator, for both lethal and nonlethal neutralization of electronic/communications equipment, and for augmentation of current and future kinetic and laser APSs at tactically useful ranges; and (3) a dazzler munition using an acoustic/light source, with an effective range from 0 to 500 meters, for temporarily rendering armored vehicle sensors ineffective.

In FY00, establish target set vulnerabilities for all three technologies, as well as MMWS architecture. During FY00/01, optimize power consumption and output for separate and combined target effects for

the laser and microwave systems, and commence design and fabrication of component hardware for all three systems. In FY02, validate dazzler munition effectiveness via static tests against threat target surrogates, and complete component integration for laser and microwave systems. In FY03, demonstrate dazzler munition range and accuracy performance, integrate the laser and microwave system components, and begin subsystem testing against surrogate target(s). In FY04, launch and operate dazzler munition to verify/validate launchability and target effects across the range spectrum. Confirm effects against surrogate target(s) for laser and microwave systems at tactical ranges.

Supports: FCS.

TSO	TRADOC POC	STO Manager
John Appel	COL Henry Hughes	Harry Moore
SAAL–TT	USAARMC	ARDEC
(703) 601–1537	(502) 624–5050	(973) 724–7932
329–1537	464–5050	880–7932

IV.WP.2000.05—LIGHT FIGHTER LETHALITY. This STO defines, develops, and demonstrates versatile, lightweight combat system technologies having a common system architecture (individual, crew, personal, mission specific) that dramatically reduce warfighter system weight, provide near 100 percent lethality, and maximize operational utility and survivability.

In FY00, established initial weapon system architecture and preliminary error budget for a dual-munition pod firing microsized, course-correcting seeker projectiles; system weight will be less than 10 pounds (threshold), 5 pounds (goal). In FY01, verify, through constructive simulation, individual system and force-on-force empirical performance, and conceptualize preliminary individual system designs. In FY03, demonstrate critical subsystem seeker projectile technologies to permit single munition weight less than 0.5 pound (T), 0.25 pound (G), and inertial guidance/course correction for a probability of incapacitation greater than 75 percent at 500 m (T), 1,000 m (G).

TSO	TRADOC POC	STO Manager
John Appel	COL Frank Stone	Matthew Zimmerman
SAAL–TT	USAIC	ARDEC
(703) 601–1537	(706) 545–1515	(973) 724–7993
329–1537	835–1515	880–7993

IV.WP.2001.01—ELECTROMAGNETIC (EM) GUN TECHNOLOGY. This STO focuses on addressing technical challenges associated with developing an EM armament, in particular with developing pulsed power for EM launchers. EM armaments offer the potential to field a leap-ahead capability by providing adjustable velocities, including hypervelocity. EM armaments would greatly reduce the sustainment requirements and vulnerabilities of conventional cannon systems. EM armaments potentially can be fully integrated with electric propulsion and electromagnetic armor systems to provide an efficient, highly mobile, and deployable armored force.

By FY01, select from two alternative pulsed-power technologies—drum topology or disk topology—and develop a detailed design (TRL 3). By FY02, complete primary pulsed power component testing and development (TRL 3). By FY03, have a functional, single rotating machine at full scale (TRL 4). By FY04, complete evaluation of the pulsed power machine using subscale launcher and projectile (TRL 4). By the end of FY06, demonstrate pulsed-power technology (rotating machines) with energy density (energy delivered to breech / mass of components) of 10 joules per gram and a robust, fieldable launcher and integrated launch package (TRL 5).

Supports: Leap-ahead lethality for future ground vehicles.

TSO	TRADOC POC	STO Manager
Cathy Kominos	John Butler	LTC Buck Tanner
SAAL–TR	DFD Fort Knox	ARL–WMRD
(703) 601–1524	(502) 624–4951	(410) 306–0662
329–1524	464–4951	458–0662

IV.WP.2001.02—SOLID-STATE HEAT CAPACITY LASER (SSHCL). The focus of this program is development of a lightweight, pulsed-laser technology for a variety of short-range, time-critical air and missile defense missions. The SSHCL program is based on technology developed by Lawrence Livermore National Laboratory. The laser beam is generated from neodymium-doped crystal slabs, which are pumped by monolithic, high-duty-cycle, high-existence diode arrays. Typical pulsewidth is several hundred microseconds with a repetition rate of hundreds of hertz. Supporting technologies have been demonstrated, which include the handling of the heat load by the laser diodes, edge cladding of glass disks, crystalline disk manufacturing techniques, and the intracavity adaptive optics wavefront controls at low repetition rates. The primary issues are in heat management of the disks, edge cladding of GGG disks, and reduction of the costs of producing the laser diodes. Developing an efficient cooling system that removes the waste heat generated by the slabs and arrays is imperative to providing a laser that meets the warfighter's operational availability requirements. The cost of the diodes will decrease due to the requirements for a pilot production program and dual use. The current flashlamp-pumped breadboard configuration will produce an average power of 10 kW with a pulse energy of 500 J, a pulse duration of 0.35 ms, and a repetition rate of 20 Hz.

By FY04, develop and demonstrate a three-disk-module SSHCL, capable of producing 15 kW, by replacing the flashlamps with diode arrays (TRL 4). By FY07, develop and deliver to High-Energy Laser Test Facility additional modules, capable of producing a weapon-scalable prototype of 100 kW (500 J @ 200 Hz), for integration with a pointer / tracker. To relieve the laser power efficiency requirements, this STO will leverage the high specific power development effort being done by ARL for DARPA. As SSHCL devices are developed, SSHCL lethality and propagation will be evaluated.

TSO	TRADOC POC	STO Manager
Mary Miller	Hank Tarkowski	Dr. Randy Buff
SAAL–TT	DCD, USAADASCH	USASMDC DE Program Office
(703) 601–1543	(915) 568–1392	(256) 955–1911
329–1543	978–1392	645–1911

SOLDIER AND PERSONNEL TECHNOLOGIES

IV.SP.1997.01—MULTIFUNCTIONAL FABRIC SYSTEM. The objective of this STO is to enhance the flame and thermal protection levels of combat uniforms without compromising other protective characteristics. The technical challenge entails the integration of low-cost flame/thermal protection into other multiple threat systems, including capabilities such as electrostatic, environmental, chemical, and signature reduction. Potential technologies for use in the system are polyphenolic material coatings, micro-encapsulation of flame suppressants, and electrospun fibers.

In FY99, established threat-based flame protection performance criteria for dismounted, mounted, and MOUT protective clothing systems and demonstrated the feasibility of combined protection with a new or improved material such as modified aramid, flame-retardant fiber blends, and novel experimental fibers. In FY00, established a test methodology for flame-resistant clothing systems while maintaining multiple threat protection levels. By the end FY01, demonstrate combined protection using novel fibers and fabric treatments resulting in a fabric system that will provide an increase in overall soldier survivability with a 30–50 percent decrease in the cost of existing flame protective systems (TRL 5).

Supports: Upgrades to LW, Air Warrior, Mounted Warrior, and MOUT; DBBL; Transportation Corps School; Quartermaster School; Engineer School.

TSO	**TRADOC POC**	**STO Manager**
Pamela Beatrice	Chris Kearns	Barry Hauck
SAAL–TT	DBBL	NSC
(703) 601–1558	(706) 545–6391	(508) 233–4097
329–1558	835–6391	256–4097

IV.SP.1997.02—INTERVEHICLE EMBEDDED SIMULATION TECHNOLOGY. This STO will develop and demonstrate the technology needed to fully embed an advanced distributed simulation system in ground combat vehicles for the Objective Force. INVEST is evolving an architecture suitable for implementation of embedded simulation (ES) in future and legacy vehicles. The program's objective is to demonstrate the feasibility of using ES to enhance future training and operational capabilities for individuals and crews of a battalion or task force. The ES concept uses data provided by digitized systems and enhances data presentation.

In FY97, assessed the state of enabling technologies for low-cost IG, concurrent player models, live-virtual integration, embedded simulation prototype, intelligent tutoring systems, and wireless LAN technology. In FY98, developed functional and performance specifications for ES/ET systems, initiated concurrent player model development, investigated a proof-of-concept demonstration of the use of intelligent tutoring systems, evaluated candidate ES communication technologies, developed the Mobile Crew Station Simulation Lab (MCSSL) for demonstrations, and developed ES interface and architecture specifications for M1A2 SEP tank. In FY99, completed the integration of IPT research products, developed ES architecture for M1A2S EP, defined A-kit-to-B-kit interfaces and intra-B-kit component interfaces, delivered 1Gen B-kit, and demonstrated virtual ESS for M1A2 SEP commander's station on MCSSL. In FY00, developed techniques for injection of virtual targets into live scenes in vehicle sensors and sights, and registration of virtual terrain database to live terrain; demonstrated virtual stationary entities on live terrain with MCSSL and digital range with BFV A3, and refined 1Gen B-kit;

demonstrated aimpoint determination on live targets, and developed ES enhancements to crew after-action reports (AARs) (TRL 3). By FY01, complete product integration, demonstrate virtual entities on live terrain on moving MCSSL, deliver 2Gen B-kit, demonstrate geo-pairing for live targets, and demonstrate ES enhancements to crew AARs (TRL 4/5).

Supports: PEO–GCSS, vehicle program managers, PM–TRADE, PM–ITTS, PM–CATT, PM–WARSIM, PM–FCS.

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos	COL William Jones	Hubert Bahr
SAAL–TR	Army Training Modernization Dir.	STRICOM
(703) 601–1524	(757) 878–2446	(407) 384–3874
329–1524	927–2446	970–3874

IV.SP.1997.03—COMPUTER-GENERATED FORCES (CGF). This STO will demonstrate intelligent CGF simulation technologies, determine the critical behavior and essential characteristics that must be exhibited, and define the methodology and computational approach for scalable CGF representation, with the capability to be reconfigurable to varying battlefield behavior.

In FY98, expanded composable behavioral prototype to combined arms representation that is dynamically programmable and reconfigurable by subject-matter experts, investigated distributed model scalability and intelligent command modeling, and transitioned ModSAF CGF Voice I/O. In FY99, addressed CGF system architectural composability, and demonstrated advanced intelligent behavior technology. In FY00-01, demonstrate significantly increased capabilities for scalable and configurable CGF representation.

Supports: ModSAF; CCTT; OneSAF; WARSIM programs; testbed/battle laboratory experimentation, demonstration, and training.

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos	Diane Scharein	H. Michelle Kalphat
SAAL–TR	Requirements Integrations Directorate (DCSCD)	STRICOM
(703) 601–1524	(757) 788–3712	(407) 384–3862
329–1524	680–3712	970–3862

IV.SP.1998.01—COGNITIVE ENGINEERING OF THE DIGITAL BATTLEFIELD. Battle command operations at brigade and above are increasingly being characterized by component capabilities that focus on the cognitive aspects of a distributed decisionmaking process. This STO responds through a focused research program aimed at better understanding these cognitive processes as they are shaped by time stress, team structure, level of staff training and experience, and introduction of digitization technology. Through experimentation and constructive exercises, the STO develops a set of predictive models and perfor-

mance metrics for assessing TOC design tradeoffs among information display and decision support technology, team structure, skill and experience level, and cognitive workload (FY99–00). The models focus on commander's intent and maintenance of a relevant common picture, addressing battle staff performance from both a data-driven perspective and a concept-driven perspective. The models and metrics are refined to address both changing OPTEMPO and asymmetric engagements (FY01–02). Research findings are used to refine a series of battle staff training approaches that address a broad range of staff officer cognitive skills and functions (FY99–02). Finally, research findings are integrated into a cognitive architecture for the battlefield—a functional roadmap for guiding R&D investments in information technology and staff officer training, battle lab experiment planning, and force development planning. The STO provides a formal mechanism for linking cognitive research activities in ARL and the Army Research Institute for the Behavioral and Social Sciences, and coordinating these programs with related activities in USASC, CGSC, ARL, BCBL, and AMBL.

Supports: Objective Force, Division XXI AWE, BC^2 ATD, RBV ACTD, CERDEC.

TSO	TRADOC POC	STO Manager
Cathy Kominos	Dick Brown	Dennis Leedom
SAAL–TR	TPIO ABCS	ARL–HRED
(703) 601–1524	(913) 684–3137	(410) 278–5919
329–1524	552–3137	298–5919

IV.SP.1998.02—BALLISTIC PROTECTION FOR IMPROVED INDIVIDUAL SURVIVABILITY. This program develops and inserts advances in materials technology that will increase the protection and performance of armor systems for the individual warfighter.

In FY99, integrated and transitioned improved technologies (at least 20 percent reduced weight for small-arms protection) to development or as technology insertions to modify existing individual protective systems. In FY00, demonstrated and inserted protective materials technology that will reduce casualties at 35 percent less system weight than the 1996 individual countermine protective systems. By the end of FY01, develop enhanced assessment criteria, including behind-armor effects for ballistic impact on personnel armor systems (TRL 5). By the end of FY03, demonstrate an improved material system prototype (over FY99 insertions) for second-generation multiple ballistic threat protection with a 25 percent decrease in weight (or an increase in protection or a combination, depending on user input) (TRL 4). Technologies with potential to satisfy this STO include advances in polymeric materials through modification of existing fibers (copolymerization of aramid, PBO), bioengineered protein-based fibers, and the synthesis of new polymers. Improved rigid materials are anticipated through DARPA and Army programs. These could include low-cost, high-performance boron carbide, new metal alloys, metal matrix composites, and potentially other new ceramics/composites.

Supports: Transportation Corps School Infantry School, Military Police School, Engineer School, DBBL, Department of Justice, Advanced Development RJS1/63747/D669—Clothing and Equipment, Engineering Development RJS1/64713/DL40—Clothing and Equipment.

TSO	TRADOC POC	STO Manager
Pamela Beatrice	Chris Kearns	Wesley Goodwin
SAAL–TT	DBBL	NSC
(703) 601–1558	(706) 545–6391	(508) 233–4538
329–1558	835–6391	256–4538

IV.SP.1999.01—LIGHTWEIGHT SOLDIER. This program defines the advanced soldier system architecture for the Objective Force timeframe with the ultimate goal of making future infantry systems as lightweight as possible— 50 pounds (23 kg) fighting load versus the current 75 pounds (34 kg). This STO will develop and apply decision and prototyping tools to assess soldier system concepts and technologies, and will be responsible for ensuring that technologies and components being developed by other agencies are well coordinated and focused on the soldier system architecture for the Objective Force. It will also refine nanotechnologies and develop novel, commercial manufacturing techniques for application to the Objective Force Soldier System. Early assessments indicate that nanotechnology offers the best opportunity for significant weight and bulk reduction (25–50 percent) through integration of capabilities at the submicroscopic level.

In FY00, validated existing soldier system models using Land Warrior system baseline data. By the end of FY01, perform laboratory-scale evaluations of nanotechnology composites, which will be exploited for use in the Objective Force architecture (TRL 2). By the end of FY02, produce prototype nanotechnology components and demonstrate a virtual prototyping tool to include cognitive engineering (TRL 3). The models and virtual prototyping technologies will be used to evaluate candidate Objective Force components, including components from CECOM, ARDEC, DARPA, ARL, and other RDECs, in terms of technical capabilities and effects on human performance, and will be made available to participating agencies. By the end of FY03, verify performance of nanotechnology composites (TRL 4) and define the architecture for the Lightweight Soldier System for transition to a 6.3 joint PM-supported STO/ATD starting in 2004. This architecture will define the future system capabilities and integration required for the 50-pound (23-kg), low-power soldier system for Objective Force.

Supports: DBBL, Infantry School, Armor School, Objective Force Warrior Program, Air and Mounted Warrior upgrades.

TSO	TRADOC POC	STO Manager
Pamela Beatrice	Chris Kearns	Patrick Snow
SAAL–TT	DBBL	NSC
(703) 601–1558	(706) 545–6391	(508) 233–5436
329–1558	835–6391	256–5436

IV.SP.1999.02—LOAD CARRIAGE OPTIMIZATION FOR ENHANCED WARFIGHTER PERFORMANCE. This program develops biomechanical methods, design guidance, physical training regimens, and predictive analytical and statistical models addressing the human locomotion and load-bearing functions of the soldier system to enhance the efficiency of over-ground movements and the fitness to fight of dismounted troops. The analytical model will be a physics-based locomotion/load carriage model to optimize clothing and equipment design and reduce the extensive amount of human testing currently required.

In FY99, determined responses (energy expenditure, pressure distributions, gait adaptations, etc.) to military load carriage under varied topographic and terrain conditions. In FY00, quantified the effects of current and developmental load-carrying gear, clothing, and individual equipment configured for specific squad positions on the biomechanics and physical performance of soldiers; and incorporated initial data into Integrated Unit Simulation System (IUSS) model. By the end of FY01, determine the manner in which volume, weight, and weight distribution of carried loads affect the biomechanical and performance parameters. Extend the gait model to accommodate varying terrain conditions. By the end

of FY02, provide guidance for design of load-carrying equipment that enhances the locomotor efficiency of dismounted personnel across a range of squad positions and realistic loads. By the end of FY03, quantify the changes in the physical status of the dismounted personnel that occur with specialized physical training programs. Incorporate soldier load-carriage response data into IUSS model, and make the physics-based load-carrying model available to equipment developers.

Supports: DBBL, Infantry School, Lightweight Soldier for Objective Force, IUSS.

TSO	**TRADOC POC**	**STO Manager**
Pamela Beatrice	Chris Kearns	Dr. Edward Hirsh
SAAL–TT	DBBL	NSC
(703) 601–1558	(706) 545–6391	(508) 233–5809
329–1558	835–6391	256–5809

IV.SP.1999.03—SIMULATION-BASED AVIATOR TRAINING. Building on previous simulator fidelity and training effectiveness work, this STO defines and validates model programs of instruction that will enable an increased use of virtual simulation devices to augment, and in some cases replace, flight hours in Army aviation training. Training methods, techniques, and processes will be developed that will reduce the Army's emphasis on live aircraft for aviation training programs.

In FY00, conducted an experiment in instrument flight training in Initial Entry Rotary Wing (IERW) training program at the Army Aviation Center. Subsequently, the program will focus on advanced qualification courses in an effort to capitalize on the continuing revolution in simulation technologies. The program seeks to move Army aviation toward its goal of reducing the current level of approximately 80 percent live aircraft-based training to a future level of 50 percent live aircraft-based training, while enhancing training effectiveness and efficiency.

Supports: USAAVNC, STRICOM, AMBL, PM–CATT (Aviation CATT/ARMS); TRADOC System Manager–Longbow, Comanche, Kiowa Warrior.

TSO	**TRADOC POC**	**STO Manager**
M. A. Fischl	COL Robert Carter	Dennis Wightman
SAAL–TR	USAAVNC	ARI Rotary Wing Aviation
(703) 601–1581	(334) 255–3320	(334) 255–2834
329–1581	558–3320	558–2834

IV.SP.1999.04—NEW ASSESSMENT TECHNIQUES TO MAXIMIZE 21ST CENTURY NONCOMMISSIONED OFFICER (NCO) PERFORMANCE. This STO determines the expected requirements of 21st century NCO jobs for two time periods: (1) through 2010 and (2) 2010-25. For each period, the program identifies the attributes and experiences that are expected to lead to successful performance on these jobs.

By FY02, develop indicators of these attributes and experiences and link with measures of performance based on NCO job requirements anticipated for the defined eras. Indicators that are found to accurately

predict success on these measures of future performance will be used to define new criteria for promoting NCOs.

Supports: DCSPER, TRADOC, U.S. Army SMA, SMA, Objective Force.

TSO	**TRADOC POC**	**STO Manager**
M. A. Fischl	SGM Ronald Tomek	Michael Rumsey
SAAL–TR	USASMA	ARI
(703) 601–1581	(915) 658–8332/8633	(703) 617–8275
329–1581	978–8633	767–8275

IV.SP.1999.05—VIRTUAL ENVIRONMENTS FOR DISMOUNTED SOLDIER SIMULATION, TRAINING, AND MISSION REHEARSAL. This program focuses on overcoming the critical challenges for dismounted soldier simulation by building on the previous efforts of the participating organizations (ARI, STRICOM, ARL's Human Research and Engineering Directorate (HRED)) in the development and use of virtual simulations.

In FY99, identified high-payoff applications for small-unit leader virtual environment training, developed a preliminary leader trainer for use as a research testbed, and improved computer-generated forces and an advanced mobility control system. In FY00, incorporated a prototype night capability and instructional feature and training strategy enhancements (TRL 4). In FY01, develop a prototype gesture recognition system and evaluate virtual environment night training capability (TRL 5). The product of this effort will be a HLA-compliant integrated prototype system based on validated requirements for dismounted soldier simulation. By FY02, implement an individual combatant simulation system that includes advanced visual, computer-controlled forces, locomotion, and training feature enhancements (TRL 6). Evaluate it as a training system, a mission rehearsal tool, and as a means of evaluating new concepts and equipment.

Supports: TRADOC, DBBL, Objective Force, PM–CATT, PM–ADS, Infantry School DOT.

TSO	**TRADOC POC**	**STO Manager**
M. A. Fischl	COL Michael Poodry	Stephen Goldberg
SAAL–TR	DBBL	ARI Simulator Systems
(703) 601–1581	(706) 545–2310	(407) 384–3980
329–1581	835–2310	970–3980

IV.SP.1999.06—ADVANCED TACTICAL ENGAGEMENT SIMULATIONS. The focus of this research program is to enable training and testing of emerging Objective Force smart, indirect, and top-attack weapons. This STO will review and implement, as appropriate, the findings and recommendations from recent studies. These include the 1997 ARI's *Training Analysis and Feedback Aids Study for Live Training Support,* STRICOM's *JRTC Upgrade Study,* and DARPA's *Technical Requirements and Feasibility Analysis of 21st Century Live Play.* Research will identify, exploit, and shape relevant tactical engagement simulation technologies through a series of prototype experimentation and development phases.

In FY00, established the virtual simulation testbed, evaluated proposed technical approaches, and updated the knowledge base with results of the simulation R&D efforts. In FY01, develop initial hard-

ware prototypes for field test and evaluation. In FY02, synthesize data from research and field tests and provide recommended technical solutions to TRADOC and AMC PMs and PEOs responsible for enhancements required at existing training and testing ranges. The research is needed to develop affordable system solutions that minimize the impact of force modernization on the communications bandwidth requirements, system power, weight, and packaging of test and training systems.

Supports: Objective Force, PM–Trade, PM–ITTS, CTC upgrades.

TSO	TRADOC POC	STO Manager
Cathy Kominos	COL Dennis Szydlowski	Troy Dere
SAAL–TR	MMBL	STRICOM
(703) 601–1524	(502) 624-7809	(407) 384–3882
329-1524	464–7809	970–3882

IV.SP.2000.01—CONDUCTING NANOCOMPOSITES AND NANOFIBERS FOR WARRIOR SYSTEMS. This STO focuses on the development of conducting lightweight, flexible, wearable materials from new polymers and composite structures for lightweight power generating devices. Potential spinoff technologies from this STO also include the development of next-generation materials for conductive textiles, electromagnetic interference (EMI) protection, and radar absorption. By combining new electrospinning technology and conductive components into novel nanofiber and nanocomposite materials, the objectives can be achieved.

In FY00, synthesized new polymers and demonstrated conductivities of 10–3 siemens/cm or higher. By the end of FY01, electrospin conductive polymers into high surface area, lightweight structures that will exhibit photovoltages in the range of 0.5–1.0 volt with current densities in the nA to $\mu A/cm^2$ range. By the end of FY02, optimize energy densities through the design of composite nanostructure systems. By the end of FY03, fabricate polymeric power devices with a minimum 30 percent reduction in weight (while maintaining or exceeding power levels of currently used devices). By the end of FY04, directly integrate flexible, lightweight power devices into warrior systems. Several promising designs will be demonstrated with integration into fabrics for uniforms and materials for shelters; they will be prototyped as small, flexible, lightweight, rugged devices for field use. Throughout this effort, these new conducting nanomaterials will simultaneously be evaluated for EMI protection and radar-absorbing capabilities. Cost reduction strategies, including scale-up production of the conductive materials and device fabrication, will also be developed.

TSO	TRADOC POC	STO Manager
Pamela Beatrice	Chris Kearns	Lynne Samuelson
SAAL–TT	DBBL	NSC
(703) 601–1558	(706) 545–6391	(978) 934–3792
329–1558	835–6391	

IV.SP.2000.02—WARRIOR SYSTEMS MODELING TECHNOLOGY. This joint STO develops the essential analytic tools to evaluate and quantify the military worth of next-generation Warrior Systems and future lightweight soldier initiatives. This is a key enabler of Simulation and Modeling for Acquisition, Requirements, and Training (SMART). The tools will capture the demanding level of human performance representation required in the RDA domain while furnishing the requirements and training domains with improved warrior representation.

In FY00, developed required scenario vignettes that will appropriately exercise warrior systems and components (TRL 3). By the end of FY01, provide algorithms, data model, and vignettes, including both battlefield and restricted terrain (e.g., rooms, hallways, tunnels, trenches) and other environmental features (e.g., lighting levels and dynamic weather) to improve the range and accuracy of combat assessments (TRL 5). By the end of FY02, implement improved close combat/MOUT algorithms that have been validated with ground truth data provided by the Human Systems/Modeling and Analysis for Warrior Systems Program (TRL 5). By the end of FY03, demonstrate a first-generation modeling capability to evaluate the combat worth of warrior systems in a close combat/MOUT environment (TRL 6). Validate Operational Requirement-Based Casualty Assessment nonlethal submodels and model extensions. By the end of FY04, demonstrate a verified and validated, HLA-compliant modeling capability to evaluate the combat worth of warrior systems in approved critical infantry squad battle drills and rifle platoon collective tasks (TRL 7). The model will additionally provide the capability to reduce program risk by 50 percent in the areas of prototype development, system downselection, concepts of deployment, and identified O&S costs.

TSO	TRADOC POC	STO Manager
Pamela Beatrice	Chris Kearns	Paul Short
SAAL–TT	DBBL	NSC
(703) 601–1558	(706) 545–6391	(508) 233–4256
329–1558	835–6391	256–4256

IV.SP.2001.01—TRAINING TOOLS FOR COLLABORATIVE WEB-BASED ENVIRONMENTS. In cooperation with TRADOC DCST, this STO combines efforts of STRICOM and ARI to introduce collaborative training into the Total Army Distance Learning Program. Eventually, it will enable education and training of forward-deployed FCS and combat service support units via Internet technologies. These technologies will provide effective methods and procedures for the use of web-based, collaborative training environments, including a diverse array of support tools such as desktop video-teleconferencing, multiplayer game technologies, and asynchronous learning tools.

In FY01, create applications and tests of different training methods and procedures in a variety of scenarios to determine how best to match training objectives with the capabilities of web-based technologies, and develop prototype collaborative web-based training environments that comply with DoD INFOSEC policy (TRL 4/5). In FY02, develop intelligent tutoring systems to provide the student "individualized" instructional support of cognitive training tasks (TRL 5/6). In FY03, develop virtual team members and virtual instructors—which allow for missing team members—supporting the "anytime-anywhere" training paradigm (TRL 6).

Supports: Army Vision, FCS.

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos SAAL-TR (703) 601–1524 329–1524	Mike Freeman BCBL(L) (913) 684–2357	Rodney Long STRICOM (407) 384–3928

IV.SP.2001.02—ADVANCED TRAUMA PATIENT SIMULATION. This STO develops a common medical modeling and simulation environment for initial, refresher, and sustainment training.

In FY01, analyze medical simulation and training requirements; design a methodology to support combat medical training; enhance triage, simulated treatment of patients, and after-action review capabilities; incorporate a link to a constructive simulation capability for generation of casualties and logistics supply data; and demonstrate a prototype (TRL 3/4). In FY02, complete prototype development; design an experiment to demonstrate that the improved system increases core competency levels and addresses the tasks identified on the Medical DoD Task List of 350 tasks; develop other metrics to assess the system functionality; and develop a methodology to assess interoperability with other systems (TRL 5). In FY03, complete test metrics, incorporate a medical simulator, and test complete system to assess interoperability (TRL 6).

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos SAAL–TR (703) 601–1524 329–1524	COL Sandy Tiernan AMEDD Center and School (210) 221–0130 552–2357	Beth Pettitt/John Hart STRICOM (407) 384–3934/–3887 970–3928

BIOMEDICAL

IV.ME.1996.01—A MULTISTAGE, MULTIANTIGEN *PLASMODIUM FALCIPARUM* MALARIA VACCINE. This research will lead to the development of a vaccine for *Plasmodium falciparum* malaria, the most serious malarial infection.

In FY00, completed all preclinical trials required to transition to advanced development a vaccine process to prevent *Plasmodium falciparum* infection in 80 percent of immunized personnel. By FY02, submit an IND for a multivalent, multistage *Plasmodium falciparum* vaccine and initiate Phase 1 studies. By FY03, complete Phase I study of the multivalent, multistage vaccine and select and submit and IND to the FDA for a combined, multivalent *Plasmodium falciparum* vaccine; transition the vaccine to advanced development.

Supports: Army Modernization Plan (AMP), Medical Annex O, "Project, Sustain, and Protect the Force: The Medical Threat Facing a Force Projection Army," (1994); TR97–026, Deployability; TR97–044, Survivability—Personnel; MD97–007, Preventive Medicine; aligns with DTO MD.02, Vaccines for the Prevention of Malaria.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Herbert Russakoff	COL Charles Hoke
SAAL–TM	CSSBL	USAMRMC
(703) 601–1532	(804) 734–0599	(301) 619–7567
329–1532	687–0599	343–7567

IV.ME.1997.01—WARFIGHTER PHYSIOLOGICAL STATUS MONITORING. Commanders increasingly require rapid access to basic information on the physiological readiness of their warfighters. A family of physiological sensors will be developed as an integral part of the research toolkit needed to gather data on warfighter status. Data will be organized and reduced through knowledge management and be used to refine predictive models and guide development of a "wear-and-forget" warfighter-acceptable warfighter physiological status monitor (WPSM). All systems will be compatible with Land Warrior and follow-on programs.

In FY99, prototyped wearable WPSM system for use at the DBBL that has wireless sensor network (activity, pulse, core and skill temperature, geolocation, metabolic cost of marching) that collects and stores information in open, standardized format. In FY00, prototyped Land Warrior compatible Dead Reckoning Module (tech insertion addressing LW requirement) capable of estimating the metabolic cost of locomotion and a soldier's body position. By FY01, use WPSM database and data acquisition and management capability to support the development and testing of model strategies to predict individual warfighter status (TRL 3). By FY02, develop knowledge management system to reduce information from WPSM and predicting performance and health risk models to only that which is essential to commanders. By FY03, develop highly reliable, automated bioelectronic and embedded environmental and imminent physiological threat sensors via enabling technologies, including real-time electroencephalogram (EEG) analysis and other indicators of mental performance (TRL 6).

Supports: TR97–944, Survivability—Personnel.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Chris Kearns	LTC Karl Friedl
SAAL–TM	DBBL	USAMRMC
(703) 601–1532	(706) 545–6391	(301) 619–7301
329–1532	835–6391	343–7301

IV.ME.1997.02—OPTIMIZATION OF PHYSICAL PERFORMANCE. This research is focused on the optimization of training programs to reduce injury of physically mismatched individuals to military tasks, and to maximize physical readiness through nonmateriel ("skin-in") solution.

In FY98, established a database of energy requirements and activity patterns for men and women in a variety of military jobs to predict and plan for voluntary energy requirements; demonstrated a reduction in training injuries through improved physical training programs during basic training; and developed physical training strategies and alternatives to prevent stress fractures in susceptible individuals. In FY99, established medical criteria to optimize efficiency and ensure safety of individual soldier equipment (combat boots, body armor, load carriage systems) for use by the equipment developers; and developed state-of-the-art, scientifically based training programs to improve performance of elite units, for special occupational requirements, and to increase opportunities of all soldiers in jobs with specific physical standards. In FY00, identified biochemical mechanisms and functional consequences of the effects of sudden increases in physical training volume and prolonged physical exertion (overtraining) for soldiers; and identified high risk for injury groups using existing outcome data. By FY01, develop strategies involving antioxidants, ergogenic aids, and physical training techniques to counter reductions in physical capacity produced by overtraining. By FY02, develop strategies, including training and other fitness and nutrition habits, to optimize bone mineral accretion in young women to reduce stress fracture, and later osteoporosis.

Supports: TR97–010, Soldier Performance Enhancement.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	LTC Dunham	LTC Karl Friedl
SAAL–TM	CSSBL	USAMRMC
(703) 601–1532	(508) 442–2928/2937	(301) 619–7301
329–1532	639–2928	343–7301

IV.ME.1997.03—LASER BIOEFFECTS AND TREATMENT. No single factor is more certain to compromise soldier effectiveness than the knowledge of battlefield threats against which there are no proven medical countermeasures. No organ is more vulnerable to the directed energy of lasers than the unprotected eye, and blindness, temporary or permanent, can occur in an instant and without warning. Medical research has demonstrated that not all forms of laser energy are equally harmful to the eye; thus, system developers can be guided away from harmful frequency/power mixes by medical exposure standards based on new research, which do not needlessly deny developers options to raise power levels or exploit fre-

quencies that pose less threat. Understanding of the bioeffects must be translated into effective field treatment interventions.

In FY97, demonstrated efficacy of early phase antiinflammatory therapy in nonhuman primate model for treatment of laser retinal trauma and identified other early phase treatment candidates; determined hazards of fast optical switch for tank sights, and established analytical methods for predicting the degree of ocular protection; and refined eye tracker model to simulate laser injury and correlate performance with human laser accident case results. In FY98, resolved discrepancies in bioeffects database for subnanosecond exposures, and updated hazards assessment and exposure limits based on operational performance criteria; determined bioeffects of broadband diodes used in advanced military display systems; developed high-resolution ophthalmoscopic imaging technology for use in telemedical assessment of laser eye injuries, and provided laser injury database for inclusion in smart far-forward medical information systems; and established performance-based models characterizing levels of visual impairment pertinent to battlefield laser injury. In FY99, developed and tested field therapy kits for laser retinal injury; and developed in vivo photoreceptor imaging in primate models to enhance assessment of laser retinal injury and repair mechanisms. In FY00, refined operational exposure limits. By FY02, refine methodologies to assess and treat laser retinal injuries; convolve high-resolution retinal imaging technology with photoreceptor transplant technology to evaluate autologous photoreceptor transplant methodology; and begin evaluation of electronic retinal implants for treatment of laser scotoma.

Supports: TR97–044, Survivability—Personnel.

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	LTC Dunham	LTC Karl Friedl
SAAL–TM	CSSBL	USAMRMC
(703) 601–1532	(580) 442–2928/2937	(301) 619–7301
329–1532	639–2928	343–7301

IV.ME.1999.01—RAPID ANALYSIS OF FOOD AND WATER FOR CHEMICAL AND MICROBIAL CONTAMINANTS. This program transitions to development a method for rapid detection of chemical and microbial contaminants in food and drinking water to validate safety for human consumption. The technologies will ensure timely evaluation of water and food safety to protect deployed forces from incidental or purposeful contamination of these vital commodities with industrial chemicals.

In FY00, demonstrated detection of at least one coliform bacterium and one class of toxic agricultural pesticide in assays compatible with water and food monitoring to select the best technology to detect unhealthy concentrations defined by DoD standard samples within 4 hours. By FY02, integrate the bacteriological and chemical assays into a breadboard system for water testing. By FY04, complete brassboard system that interfaces with CW/BW water monitoring system. Apply similar technology to the testing of food samples.

Supports: MD97–004, Combat Support in an NBC Environment; QM97–013, Water Purification and Treatment; links to DTO MD.10, Deployment Toxicology Technologies.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Warren Dixon	LTC Karl Friedl
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7301
329–1532	680–4413	343–7301

IV.ME.1999.02—FUSION OF WARFIGHTER PERFORMANCE, ENVIRONMENTAL, AND PHYSIOLOGIC MODELS. This program provides technical data on physiologic functions under complex environments to estimate soldier performance in training and combat. The completed integrated mathematical computerized system will reduce physiologic injuries due to environmental stresses.

In FY99, prepared a model for reliable prediction of response to cold stress. In FY00, prepared a neural network model of human fluid compartments to predict injuries due to water imbalance. By FY02, prepare a model of peripheral and central cardiovascular function during operations. By FY03, prepare a pulmonary model for altitude sickness and high-altitude pulmonary edema.

Supports: DBS97–021, Survivability—Active Capabilities; MD97–007, Preventive Medicine; links to DTO MD.01, SUSOPS Enhancement; DTO MD.19, Optimization of Physical Health and Readiness.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Warren Dixon	LTC Karl Friedl
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7301
329–1532	680–4413	343–7301

IV.ME.1999.03—PREVENTION OF DIARRHEAL DISEASES. This STO transitions to advanced development individual and combined vaccines to prevent the most common bacterial pathogens that cause diarrhea in deployed forces. Each vaccine should reduce disease caused by a specific microorganism by 80 percent.

By FY01, transition to advanced development a *Shigella sonnei* vaccine (TRL 6). By FY02, transition to advanced development of a *Shigella dysenteriae* vaccine (TRL 6). By FY03, transition to advanced development an improved enterotoxigenic *Escherichia coli* vaccine (TRL 6) and an improved Campylobacter vaccine based on recombinant protein(s) (TRL 6).

Supports: TR97–026, Deployability; TR97–029, Sustainment; TR97–044, Survivability—Personnel; MD97–007, Preventive Medicine; links to DTO MD.06, Prevention of Diarrheal Diseases.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	CPT Mark Morano	COL Charles Hoke
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–2539	(301) 619–7567
329–1532	680–2539	343–7567

IV.ME.2000.01—OPTIMIZATION OF VISUAL PERFORMANCE WITH OPTICAL AND ELECTRO-OPTICAL SYSTEMS AND MATERIALS. The Army is equipping its soldiers and its vehicles with advanced imaging and display technologies to solve battlefield problems such as degraded fighting environments (e.g., low illuminance, smoke, fog) and directed-energy, chemical, and biological weapons. Inadequate bioengineering testing and evaluation to ensure a match with human characteristics frequently leads to fielded nonmedical systems that exhibit degraded performance. This STO produces improved image output standards to optimize visual performance with advanced electro-optical designs and visual performance models to predict soldier performance in an operational environment.

In FY00, developed test design for evaluating Integrated Helmet and Display Site System (IHADSS) imagery in the field; and developed display assessment for shades-of-gray model for head-mounted displays (HMDs) in an operational environment. By FY01, investigate visual performance issues relating to binocular/biocular HMDs. By FY02, develop methods for assessing the effects on performance of gray-level perception in HMDs; determine compatibility tradeoffs of image intensification devices with color multifunction displays; and develop spatiotemporal model of human contrast sensitivity. By FY03, develop performance criteria for the integration of flat panels into HMDs. By FY04, determine visual performance deficits with electro-optical devices relating to refractive correction methods; and complete visual detection model to include complex targets and backgrounds.

Supports: TR97–017, Information Display; TR97–002, Situation Awareness.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Warren Dixon	LTC Karl Friedl
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7301
329–1532	680–4413	343–7301

IV.ME.2000.02—PERFORMANCE ENHANCEMENT AND INJURY PREVENTION IN HOT ENVIRONMENTS. The capability to operate in all environments lies at the heart of the force projection concept guiding strategic planning. Soldiers participating in almost all military deployments (including those in arctic regions) will encounter heat stress that must be managed for successful mission accomplishment and avoidance of heat illness and injury. This is especially true in desert and jungle climates; for example, approximately 20,000 Egyptian soldiers died from heat injuries during the 1967 Six-Day War, and in Granada, about 4 percent of U.S. forces were treated at Battalion Aid Stations each day for heat illness. Soldiers encounter heat stress from a complex interaction of climatic conditions, physical work intensity, health/nutritional status, clothing worn, and equipment characteristics. This program establishes the scientific foundation for Army doctrine directed to manage and minimize adverse effects of heat stress.

In FY00, demonstrated the impact of physiological factors (e.g., muscle injury and inflammation) and behavioral factors (e.g., smoking) that affect thermoregulation and susceptibility to heat stress. By FY01, demonstrate efficacy of local vasodilators to maximize regional dry heat loss via manipulation of current microclimate cooling techniques; and demonstrate feasibility of interventions (e.g., melatonin) to improve restorative sleep in the heat. By FY02, assess the magnitude and relative benefits of physiological adaptations (heat acclimation, phase shifts, etc.) to thermal comfort and mental performance during heat stress. By FY03, identify possible genetic markers of heat injury susceptibility. By FY04, transition to advanced development a family of customized heat acclimatization strategies to optimize thermo-

regulation and tissue protection, including drug prophylaxes and treatments discovered in earlier basic research (e.g., calcium channel blockers, regulators of heat shock proteins, and monoclonal antibodies to inflammatory cytokines or lipopolysaccharides).

Supports: TR97–044, Survivability—Personnel.

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	Warren Dixon	LTC Karl Friedl
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7301
329–1532	680–4413	343–7301

IV.ME.2000.03—PHARMACOLOGICAL STRATEGIES TO ENHANCE MENTAL PERFORMANCE IN FATIGUED SOLDIERS. Specific pharmacological countermeasures will be developed to sustain performance when adequate sleep is not possible and to optimize the recuperative value of sleep or adjustment to new time zones when the opportunity for sleep is presented or is impaired (e.g., by circadian factors, environmental noise, or light). Candidate interventions with potential high payoff are stimulants (e.g., dexedrine, modafinil) for performance sustainment, short- and medium-acting hypnotics (e.g., temazepam, zolpidem) for sleep induction, and melatonin for rapid reentrainment of disrupted circadian rhythms. This STO produces field medical guidance and FDA approval for secondary indication uses of existing products.

In FY00, determined the upper limits of effectiveness of drug interventions in operational emergencies with study of proven alertness drug treatment at an extreme of sleep deprivation (dexedrine at 112 h); and transitioned caffeine research, including data on formulations, optimal dosing, and effects in habituated and nonhabituated users, to a caffeine product or guidance for caffeine use in the field (Milestone B review/The Surgeon General's approval). By FY01, demonstrate modafinil efficacy for militarily relevant performance sustainment (in flight; in field environments); determine efficacy of sleep inducers (and reawakening agents) for improved performance in field environments; and conduct Milestone A review. By FY02, demonstrate efficacy of resynchronizing drugs for accelerating performance restoration following large phase shifts in eastward and westward deployments. By FY03, transition modafinil out of technology base research, providing data on efficacy of modafinil compared with amphetamine and high dose caffeine; and provide guidance on SUSOPS/CONOPS mental performance decrement countermeasures based on comparative field evaluations of available strategies.

Supports: TR97–044, Survivability—Personnel; TR97–029, Sustainment.

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	Warren Dixon	LTC Karl Friedl
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7301
329–1532	680–4413	343–7301

IV.ME.2000.04—INJURY PREVENTION AND RESTRAINT TECHNOLOGIES FOR GROUND VEHICLES AND HELICOPTERS. Traditionally, military ground vehicles have not been equipped with state-of-the-art safety equipment, but significant improvement in occupant safety in tracked and wheeled tactical vehicles can be realized through integration of commercial automotive technology and current military aviation restraint systems. Occupant flail with resultant head injury is the leading cause of fatality and serious injury in Army helicopter accidents; a potentially effective countermeasure to flail injuries is the Cockpit Airbag System (CABS). Performance and safety concerns regarding CABS design range from the unique characteristics of a helicopter crash pulse to the effects of unintended airbag deployment ion injury and aircraft control. At least a 25 percent reduction of head and upper torso injury can be achieved with current inflatable restraint technology. Residual hazards related to ride quality (e.g., repeated jolt) must be quantified and assessed as part of a complete health hazards assessment (HHA) program. However, no standard for HHA of repeated jolt exists. This STO develops generic assessment methodologies and injury probability models, integrates the results into design parameters for restraint system configuration and performance, and transitions research findings to a national standard (ANSI) for repeated jolt.

In FY00, determined the effects of CABS deployment on flight performance, conducted epidemiological review of occupant injuries in military vehicles, surveyed industry for new or improved occupant restraint technologies, and produced interim HHA method and standard for repeated jolt. By FY01, determine effects of CABS deployment on upper extremity injury, correlate occupant injuries with restraint system performance, and conduct field studies into repeated jolt during ground troop training exercises. By FY02, deliver model of airbag-aircrew interaction in rotary-wing crash environment, recommend CABS fire thresholds, and propose injury probability models and performance metrics. By FY03, complete restraint metric development, determine acceptable injury thresholds for dynamic responses in restraint systems, and transition repeated jolt guidelines and proposed standards for safe operations of tactical ground vehicles. By FY04, deliver technical data package on proposed medical and biodynamic performance standards for effective military restraint systems.

Supports: TR97–044, Survivability—Personnel; AV97–007, Aviation—Survivability.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Warren Dixon	LTC Karl Friedl
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7301
329–1532	680–4413	343–7301

IV.ME.2000.05—INNOVATIVE STRATEGIES TO ASSESS HEALTH RISKS FROM ENVIRONMENTAL EXPOSURE TO TOXIC CHEMICALS. Military deployments over the last 30 years have raised concerns about potential health hazards to soldiers exposed to toxic industrial/agricultural chemicals (TICs) and military relevant chemicals (MRCs) (not including NBC chemicals). The development of new munitions, the increasing number of women in military deployments, and the increased awareness of chemical contaminants from past industrial operations on military installations have raised concerns about the effects of environmental exposures to chemicals on human health, reproduction, birth defects, resistance to disease, and other health issues over the lifetime of the soldier. This research develops low-cost sensitive screening tools and instrumented animal models (sentinel species) to assess health risks from environmental exposures to TICs, MRCs, and chemical mixtures.

In FY00, demonstrated the useful application of the Frog Embryo Toxicity Assay, Xenopus (FETAX) assay as a screening tool to evaluate the MRCs (TNT, RDX, HMX, perchlorate, and their breakdown products), and select mixtures, for their ability to cause birth defects. By FY01, develop a neurotoxicity assay in an alternative species for evaluating individual MRCs and select mixtures. By FY02, develop an immunotoxicity assay in an alternative species for evaluating MRCs, including permethrine and heavy metals, and select mixtures. By FY03, develop reproductive toxicity assays (male and female) in alternative animal species for evaluating MRCs and select mixtures. By FY04, develop and field-test a free-ranging species for monitoring chemical contamination in water.

Supports: MD97–007, Preventive Medicine; MD97–010, Medical Laboratory Support.

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	Warren Dixon	LTC Karl Friedl
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7301
329–1532	680–4413	343–7301

IV.ME.2000.06—INHALATION INJURY AND TOXICOLOGY MODELS. The purpose of this program is to develop physiologically based predictive models of injury, incapacitation, and degraded performance relevant to military scenarios involving inhaled toxic substances (e.g., MOUT on smoke-filled buildings, armored vehicles penetrated by offensive rounds, fires in enclosed spaces). This research defines the interactive physiology and biochemistry of reactive oxygen, nitrogen, and other chemical species that play a critical role in tissue injury from toxic inhalation. It focuses on representative irritant and narcotic gases while creating a framework that can accommodate other gases. These models will be combined with thoracic injury models to predict actual exposures and outcomes to combined injury problems (e.g., blast and toxic gas exposures in enclosed spaces).

In FY00, described pathophysiology of combined fire gas exposure for incorporation into combined gas injury incapacitation predictive models, using scaling rules developed to extrapolate data from small and large animals to humans. By FY01, develop biomarker for inhalation injury based on oxidative stress and other mechanisms of inhalation lung injury. By FY02, validate predictive model of toxic gas incapacitation in enclosed spaces, including particle and aerosol inhalation; and ensure that halon alternative, JP8 fuel, and refrigerant/lubricant issues are addressed. By FY03, extend model to include effects of physical exertion, combining new experimental data and understanding of oxidative stress and toxic gas interactions. By FY04, extend model to include environmental stressors (heat, cold, and altitude) and to address thoracic injury/blast interactions.

Supports: TR97–044, Survivability—Personnel.

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	Warren Dixon	LTC Karl Friedl
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7301
329–1532	680–4413	343–7301

IV.ME.2000.07—NUCLEIC ACID (DNA-BASED) VACCINES TO PREVENT DENGUE. This STO seeks to demonstrate 80 percent protection of primates from challenge with all four serotypes of dengue viruses, as measured by lack of viremia or greatly reduced viremia, and to demonstrate safety and tolerability (with minimal reactogenicity) in humans, and immunogenicity in humans.

In FY00, demonstrated some protection of primates against all four dengue serotypes with a tetravalent vaccine, protected 67 percent of primates against one serotype with a monovalent vaccine, and submitted IND application to the FDA. By FY01, protect 67 percent of primates against all four serotypes, protect 80 percent primates against one serotype, achieve Milestone A, and obtain IND classification from the FDA. By FY02, protect 80 percent of primates against all four serotypes. Complete Phase 1 human trial of monovalent (one serotype) vaccine: maximum tolerable dose established for dengue DNA vaccines. By FY03, complete Phase 1 human trial of tetravalent (four serotypes) vaccine. By FY04, complete initial Phase 2 human immunogenicity trial: demonstrate neutralizing antibody to all four serotypes; narrow dose and schedule choices based on immunity with minimal side effects (Milestone B).

Supports: AMP, Medical Annex O, "Project, Sustain, and Protect the Force by Development of NBC Agent Preventive Measures"; TR97–029, Sustainment; TR97–044, Survivability—Personnel.

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	Warren Dixon	COL Charles Hoke
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7567
329–1532	680–4413	343–7567

IV.ME.2000.08—DEVELOPMENT OF A NEW STANDARD MILITARY INSECT REPELLENT. Compliance for use and potential toxicity problems with the current military insect repellent have resulted in a requirement for a replacement product. Because no commercially available repellents meet Army requirements, new effective repellent compounds and leading-edge formulation technologies will be explored and prioritized to develop a new military insect repellent that is completely acceptable to the user and maintains its effectiveness under combat conditions. This new repellent will offer the greatest tactical flexibility of any arthropod-borne disease prevention strategy. Repellents can be applied effectively to prevent any arthropod-borne disease, whether or not surveillance has identified the pathogen. Repellents are often the only means of protection against arthropod-borne diseases in combat environments when vector control measures are not possible or when the speed of military developments prevent the use of chemoprophylaxis or vaccines.

In FY00, prioritized new repellent compounds in the laboratory against vectors of malaria, dengue, scrub typhus, leishmaniasis, Lyme disease, and rickettsioses. By FY01, perform toxicological evaluations on the most effective compounds. By FY02, evaluate safe compounds on human skin against disease vectors in the laboratory. By FY03, select formulation for new repellent compounds that maximizes user acceptability and that resists loss from abrasion and wetting. By FY04, evaluate formulated repellent compounds by field testing on human skin against disease vectors and downselect to the best formulation to exit Acquisition Phase 0 and enter Acquisition Phase I.

Supports: TR97–044, Survivability—Personnel; MD97–002, Preventive Medicine.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Warren Dixon	COL Charles Hoke
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7567
329–1532	680–4413	343–7567

IV.ME.2001.01—HEAD-SUPPORTED MASS (HSM): WARFIGHTER HEALTH AND PERFORMANCE. The Army depends on head-supported devices (HSDs) ranging from basic ballistic and impact protective helmets to advanced weapon sighting and communication systems. These devices increase the amount of weight supported by the soldier's head and neck and usually shift the center of HSM upward or forward, placing the user at risk of acute and chronic neck injury and degraded warfighter performance. Medical and safety personnel do not have validated guidelines to help assess problems with fielded systems, and sufficient data do not exist for Army materiel developers. This STO enables the informed and safe use of current and future HSDs. This research will produce an integrated model incorporating HSD design criteria, operational guidelines, and health risk criteria that will minimize performance degradation and reduce the risk of injury.

By FY01, complete retrospective epidemiological studies of neck injury in operational environments (TRL 3). By FY02, characterize the HSM-related mechanical stresses of operational environments (TRL 4). By FY03, establish HSM neck injury thresholds and performance criteria (TRL 4). By FY04, complete predictive models for neck injury and human performance with varying HSM (TRL 5). By FY05, transition integrated model of design and health risk criteria to customers (TRL 6).

Supports: TR 97–023, Mobility Combat Dismounted; TR 97–002, Mobility-Combat Mounted.

TSO	TRADOC POC	STO Manager
LTC Lorna VanderZanden	Warren Dixon	LTC Karl Friedl
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7301
329–1532	680–4413	343–7301

IV.ME.2001.02—OPTIMAL PARAMETERS FOR THE BATTLEFIELD RESUSCITATION OF COMBAT CASUALTIES. There is currently a large controversy over the optimal strategy for the resuscitation of casualties on the battlefield, there is also inefficient data to allow the selection of the optimal resuscitation fluid for use in this unique environment. Medical experts are in consensus that optimal resuscitation with the optimal fluid will save some lives that are currently lost. This effort will provide a resuscitation strategy for combat casualties that have suffered severe blood loss and are expected to have long delays before evacuation from the battlefield.

By FY03, determine the best FDA-approved or -soon-to-be-approved resuscitation fluids to prevent early and late post-resuscitation deleterious sequelae and to improve survival (TRL 4). By FY05, define

the longest period of time that hypotensive resuscitation can safely be employed using current resuscitation fluids and define an optimum resuscitation strategy (TRL 6).

Supports: DTO MD.NEW.04, Far-Forward Treatment of Trauma; MD97–003, Patient Treatment and Area Support; MD97–005, Far-Forward Surgical Support.

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	Warren Dixon	COL Robert Vandre
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7591
329–1532	680–4413	343–7591

IV.ME.2001.03—HEMORRHAGE CONTROL. Hemorrhage is the leading cause of death from wounds on the battlefield, accounting for more than 50 percent of all deaths. This effort will develop products that can be applied at the time of wounding by medics, combat lifesavers, and others at echelon I to control bleeding and thereby to reduce battlefield casualty killed-in-action rates.

By the end of FY02, demonstrate an improved tourniquet for battlefield use (TRL 6), and produce a prototype, intraoperative high-intensity focused ultrasound (HIFU) device (TRL 6) that can stop bleeding inside organs when placed on the organ surface. By the end of FY04, deliver advanced tourniquet use guidelines (TRL 7) and attain Milestone A for a candidate hemostatic agent that can be used nonsurgically to treat intra-abdominal and intrathoracic hemorrhage (TRL 5). By the end of FY05, attain Milestone A for intravenous drugs that will slow or stop internal bleeding (TRL 5), produce a prototype transdermal HIFU (TRL 6) device that can stop severe internal bleeding without the need for surgery (this is a combined Army–Navy effort), and identify drugs to restore clotting function during hypothermia (TRL 7).

Supports: DTO MD.NEW.03, Hemorrhage Control; MD97–003, Patient Treatment and Area Support; MD97–005, Far-Forward Surgical Support.

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	Warren Dixon	COL Robert Vandre
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7591
329–1532	680–4413	343–7591

IV.ME.2001.04—BLOOD PRODUCTS. Current blood products such as frozen plasma and liquid red cells present a tremendous logistical burden on the battlefield. They must be kept in special refrigerators. In addition, there is no way to determine quickly if blood is infected or to disinfect blood to allow safe transfusions directly from one soldier to another when blood supplies run out. This STO will enhance soldier survivability by providing safe, effective, and reliable transfusion medicine capabilities in far-forward and remote locations and reduce the logistic footprint with the following technologies in support of DTO MD.03: (1) rapid screening of blood-borne pathogens (BBPs) in blood donors, (2) rapid inactiva-

tion of BBP in whole blood and blood products, (3) freeze-dried plasma prepared in bags that provide storage at a wide range of temperatures and optimal activity of blood clotting factors, (4) storage bags that reduce loss of frozen blood products, and (5) collection/storage bags that enhance freeze drying of blood components.

By FY02, transition bag for frozen blood product storage (TRL 4); by FY04, transition bag for enhancement of freeze-dried plasma (TRL 6); by FY05, transition screening and inactivation of blood-borne pathogens (BBP; HIV I/II, HTLV I/II, Hepatitis B, Hepatitis C, leishmania, rickettsiae, and malaria) (TRL 6).

Supports: Medical Readiness Strategic Plan (MRSP) 2004; MD97–003, Patient Treatment and Area Support; MD97–005, Far-Forward Surgical Support.

TSO	**TRADOC POC**	**STO Manager**
LTC Lorna VanderZanden	Warren Dixon	COL Robert Vandre
SAAL–TM	ATCD–SN	USAMRMC
(703) 601–1532	(757) 788–4413	(301) 619–7591
329–1532	680–4413	343–7591

ENGINEERING, COMBAT CONSTRUCTION, MOBILITY, AND COUNTERMOBILITY

IV.EN.1997.01—SUSTAINABLE MILITARY USE AND STEWARDSHIP OF ARMY LANDS. This program improves military access to and stewardship of training and testing lands through improved knowledge bases and predictive tools that integrate multiple landscape factors into decision aids for military land use planning, management, and mitigation.

In FY00, developed measures to match land use with environmental conditions affecting land capacity. By FY01, provide simulation tools for erosion management and land rehabilitation options to restore and maintain lands for sustained use; and provide better understanding of cause-and-effect relationships and models to simulate mission impacts on key protected species. By the end of FY02, provide a military land management decision support capability integrating erosion, land use and rehabilitation, and species impact assessment with land capacity. Benefits include improved training realism and safety, reduced maintenance costs for equipment and land, increased flexibility in land use, up to 50 percent reduced constraints on access to land, and reduced fines due to environmental compliance.

Supports: National Environmental Policy Act; Endangered Species Act; National Historic Preservation Act; Clean Water Act; FOC EN 97–027, Environmental Stewardship

TSO	TRADOC POC	STO Manager
Jeff Messmore	Larry Allen	Bill Severinghaus
SAAL–TR	MANSCEN	CEERD-TD
(703) 601–1523	(573) 596–0131, x3–7264	(217) 373–6769
329–1523	581–0131	

IV.EN.1997.02—MUNITIONS PRODUCTION COMPLIANCE TECHNOLOGY. This program develops industrial installation compliance technologies to enable the Army industrial facilities to maintain production capability while achieving a 20–30 percent reduction in compliance costs under existing and projected effluent limitations.

In FY99, completed bench-scale studies of energetic degradation under sulfate reducing conditions; and implemented sequential bioreactor technology for treatment of energetic contaminated industrial facility waste to substantially reduce the capital and operating costs of Army industrial facilities. By the end of FY01, provide reductive electrochemical processes for treating energetic (propellants, explosives, and pyrotechnics) waste streams contaminated with nitroaromatics, nitramine, or nitrate esters that will meet discharge permit limits with a lower cost and greater operational flexibility than conventional technology. Current treatment and disposal costs range from $200 to $300 per ton; the goal is a 20 percent reduction in treatment costs. One installation alone can generate in excess of 4,500 tons of energetic contaminated wastewater per year. The benefit of this technology is compliance with existing and evolving environmental regulations while allowing production that is unencumbered by environmental concerns.

Supports: AMC manufacture of ammunition for tri-services; FOC EN 97–027, Environmental Stewardship.

TSO	TRADOC POC	STO Manager
Jeff Messmore SAAL–TR (703) 601–1523 329–1523	Larry Allen MANCEN (573) 596-0131 x3–7264 581–0131	Gary Schanche CEERD (217) 373–7275

IV.EN.1998.01—AIRFIELDS AND PAVEMENTS TO SUPPORT FORCE PROJECTION. This program provides improved pavement criteria for design, repair, and material systems that will result in reduced DoD pavement construction costs (approximately $72 million per year in FY95 dollars), increased pavement reliability (approximately 20 percent), and reduced pavement construction effort (approximately 10 percent) in the theater of operation. The criteria consist of material specifications, construction practices, and pavement system design and evaluation models. This is a critical requirement for force strategic deployment from CONUS and operational employment in the theater of operation.

In FY98, provided criteria for reliable airfields and pavements to support current-generation military aircraft and vehicles through the use of local materials (which may be of inferior quality) and pavement binder modifications. This extends the functional life of a pavement by 1 year ($250,000 life-cycle savings based on a 10,000-foot long runway). New technologies will be required for nonlinear viscoelastic and viscoplastic materials behavior affecting airfield and pavement performance. In FY99, provided criteria for construction, design, and repair systems to decrease construction effort by 10 percent for expedient surfaces in the theater of operation for military aircraft and vehicles. By the end of FY02, provide criteria for reliable airfields and pavements to support multiple passes of proposed future-generation aircraft and military vehicles. Design, construction, and rehabilitation of Army and Air Force airfields is an Army Corps of Engineers responsibility under Project Reliance.

Supports: FOCs EN 97–015, Procurement and Production of Construction Materials; EN 97–016, Rapid Airfield and Helipad Construction and Repair.

TSO	TRADOC POC	STO Manager
Jeff Messmore SAAL–TR (703) 601–1523 329–1523	Larry Allen MANSCEN (573) 596-0131 x3–7264 581–0131	Dr. David Pittman CEERD (601) 634–3304

IV.EN.1998.02—FORCE PROTECTION ON THE BATTLEFIELD. This STO develops concepts and criteria for protecting and concealing deploying forces from conventional weapon threats using indigenous or predesigned state-of-the-art materials.

In FY99, provided sprayable, multispectral tonedown agents for large-area signature reduction. By the end of FY01, provide expedient protective concepts for key assets in forward logistics supply points,

develop assessment procedures for the evaluation of the structural safety and protection provided by bunker and fighting emplacements, and provide designs for fixed/long-dwell facility decoys. By the end of FY02, provide ballistic and low-signature protection for base clusters in tactical assembly areas by reducing target acquisition distances and increasing survivability from battlefield weapon threats by 30 percent.

Supports: FOCs TR 97–044, Survivability—Personnel; TR 97–045, Camouflage, Concealment, and Deception.

TSO	TRADOC POC	STO Manager
Jeff Messmore	Larry Allen	Dr. Reed Mosher
SAAL–TR	MANSCEN	CEERD
(703) 601–1523	(573) 596–0131, x3–7264	(601) 634–3956
329–1523	581–0131	

IV.EN.1998.03—LINES-OF-COMMUNICATION (LOC) ASSESSMENT AND REPAIR. This STO develops (by the end of FY02) the technologies required for assessment of in-theater road networks; assessment, classification, and rehabilitation of in-theater bridges; and use of low-quality or local materials for in-theater construction to increase road construction productivity per engineer battalion by 150 man-hours per day. The capabilities provided by these technologies are critical to successful execution of the strategic, operational, and tactical engineering mobility missions required to support the Objective Force projection.

In FY00, provided materials and techniques to maintain and repair in-theater operating surfaces while increasing productivity by 150 man-hours per battalion per day.

Supports: FOCs EN 97–003, Portray a Common Terrain to the Force; EN 97–004, Engineering Reconnaissance.

TSO	TRADOC POC	STO Manager
Jeff Messmore	Larry Allen	Dr. David Horner
SAAL–TR	MANSCEN	CEERD
(703) 601–1523	(573) 596–0131, x3–7264	(601) 634–2481
329–1523	581–0131	

IV.EN.1998.04—FORCE PROTECTION AGAINST TERRORIST THREATS. This STO provides the technology for assessing the risk and protecting the force from the effects of terrorist weapons, including small arms, rockets, mortars, and vehicle bombs. It includes analytic software for calculating blast loads on structures, incorporating shielding effects of blast walls and other buildings; methods for predicting damage to structures and building components and the associated hazard to personnel; and effective techniques for retrofitting windows, doors, walls, and roofs.

In FY99, developed methods to use high-performance materials to increase the penetration resistance of structural components. By the end of FY01, develop techniques for retrofitting existing structures and

mitigating the effects of terrorist impact/fragmentation weapons and vehicle bombs. By the end of FY02, develop procedures to assess the vulnerability of structures that house military forces and methods to mitigate terrorist weapon effects, and retrofit vulnerable building components to reduce required blast standoff distances by 40 percent.

Supports: FOCs: TR 97–044, Survivability—Personnel; EN 97–012, Enhance Force Protection.

TSO	TRADOC POC	STO Manager
Jeff Messmore	Larry Allen	Dr. Reed Mosher
SAAL–TR	MANSCEN	CEERD
(703) 601–1523	(573) 596–0131, x3–7264	(601) 634–3956
329–1523	581–0131	

IV.EN.1999.01—ENVIRONMENTAL CLEANUP. This effort provides cheaper and more effective technologies for site assessment and treatment of contaminated soils and groundwater.

In FY99, developed explosives and energetics exposure and effects models for use during site environmental risk assessments, thus reducing cleanup design costs by 20 percent by cutting risk analysis time in half (reduce from years to months). In FY01, implement in situ heavy metals extraction for lead, reducing treatment costs by half (from $100-$300 per ton of soil to $50-$150 per ton) and allowing treatment below existing structures (which is currently not possible); develop in situ biotreatment processes for TNT, reducing costs from $100-$500 per cubic yard in FY98 to $25-$75 per cubic yard; and provide fate and transport risk assessment models and simulations for explosives and energetics that provide rapid contaminant fate predictions, improved risk assessment, and reduced design costs, thus allowing all risk assessments to be completed onsite. By FY02, provide advanced groundwater remediation technologies for TNT, providing increased treatment efficacy and flexibility with overall cost reduction from $1-$5 per kgal in FY95 to $0.10-$2.00 per kgal; and provide advanced visualization in support of onsite assessment during all cleanup phases, providing a 50 percent reduction in time (from months to weeks) for data analysis and treatment selection.

Supports: Substantially reduces O&S costs of remediating contaminated groundwater and soils of installation restoration, base realignment and closure, and former used defense site activities; FOCs: CM 97–015, Environmental Stewardship.

TSO	TRADOC POC	STO Manager
Jeff Messmore	Larry Allen	Dr. John Keeley
SAAL–TR	MANSCEN	CEERD
(703) 601–1523	(573) 596–0131, x3–7264	(601) 634–3477
329–1523	581–0131	

IV.EN.1999.02—BURIED UNEXPLODED ORDNANCE (UXO). This STO reduces UXO site remediation costs by significantly reducing the time and effort currently being spent on excavating nonhazardous items (nuisance alarms) while maintaining optimum P_d. This is being accomplished by defining the role of site conditions on sensing and discrimination of UXO to provide a foundation for more robust and physically based multisensor data fusion.

In FY00, obtained comprehensive sensor performance specifications (P_d, nuisance-alarm rates, false-alarm rates, and ROC curves) for UXO target, environmental, geophysical, and clutter combinations using advanced electromagnetic, magnetic, ground-penetrating radar, and chemical sensors. By FY01, develop validated UXO signature models of emerging sensors to support multisensor system development and improved analysis techniques. By FY02, develop UXO sensing and analysis technologies that reduce nuisance-alarm rates by 70 percent over a wide variety of conditions while maintaining the current P_d levels.

Supports: Supports environmental restoration at Army former used defense sites, base realignment and closure, and active training ranges. An estimated 11,000,000 acres of land is suspected of containing UXO. FOCs: EN 97–009, Operate Freely in a Mine/UXO Threat Environment; CM 97–015 Environmental Stewardship.

TSO	TRADOC POC	STO Manager
Jeff Messmore	Larry Allen	Dr. John Keeley
SAAL–TR	MANSCEN	CEERD
(703) 601–1523	(573) 596–0131, x3–7264	(601) 634–3477
329–1523	581–0131	

IV.EN.2000.01—ADVANCED BRIDGING VIRTUAL PROTOTYPING TECHNOLOGY. This STO addresses survivability, mobility, and operational enhancements of advanced bridging technologies. The use of virtual prototyping and finite element modeling (FEM) simulations allows for the study of a variety of configurations and combinations prior to fabrication and testing. This evaluation will determine an efficient design and mode of operation with the FCS. The Objective Force gap requirements for assault bridging—in-stride gap crossing up to 24 meters—will remain unchanged as requirements are based on worldwide regional terrain studies. Objective Force load requirements—Military Load Class 70—will also remain unchanged as legacy systems (i.e., Abrams and Crusader) will still be in the field. Specific technologies include advanced lightweight structural materials, virtual prototyping simulation, finite element modeling and simulation, and kinematics. This program leverages technologies developed and demonstrated by the Composite Armored Vehicle ATDs and the DARPA Bridge Infrastructure Renewal program. The goal is to achieve a 50 percent reduction in the weight of military bridges.

In FY00, conducted baseline data gathering of composite-based component performance to aid in the development of models. By FY01, conduct composites-versus-metallics studies and initiate virtual prototype simulations of launching techniques using the FCS as the launching vehicle. By FY02, initiate Finite Element Model (FEM) weight reduction and enhancement performance studies. By FY03, complete the virtual prototype and FEM weight reduction and enhancement performance studies.

Supports: FCS, Future Heavy Dry Support Bridge, Line of Communication Bridge,

TSO	TRADOC POC	STO Manager
John Appel SAAL–TT (703) 601–1537 329–1537	COL Kingston/COL Moldenhauer USAES–DCD (573) 563–4076/(573) 563–4082 676–4076/676–4082	Brian Hornbeck TARDEC (810) 574–5608 786–5608

IV.EN.2000.02—OBSTACLE MARKING AND VEHICLE GUIDANCE. This STO comprises three concepts: digital marking, smart minefield marker, and vehicle guidance. In the first concept, GPS is used to digitally "mark" the centerline of the vehicle's path from a starting point to a finishing point as directed by the operator. This breached path is represented digitally in the Army's digitized battlefield. Battle commanders' and other vehicle crews will be able to see this digitally represented breached path or cleared route three dimensionally in conjunction with the terrain. In the second concept, as the breaching or proofing vehicle proceeds through the obstacle or minefield, it will dispense "smart" markers. These markers will have a transmitter-receiver that can identify and communicate with vehicles in their proximity, an IR light emitter, and a visible light emitter. The visible and IR light emitter can be remotely turned on or off and can be programmed to operate on a schedule. In the third concept, vehicles that need to pass through the breached, proofed path will have a capability to visually guide themselves through it. Crews will see the safe path on their displays and, as they proceed, the crew will make sterring corrections using easily identifiable reference points.

In FY00, completed conceptual analysis of standard marking system requirements to provide criteria to support the concepts of this STO. By FY01, award a software development contract for digital marking and vehicle guidance; and award a contract to develop a prototype "smart" marker. By FY02, complete software development; estimate life-cycle savings; and provide MMBL with a brassboard prototype smart marker system to model battlefield marking and vehicle guidance, with the goal of a 50 percent decrease in effort to emplace markers.

Supports: FCS.

TSO	TRADOC POC	STO Manager
John Appel SAAL–TT (703) 601–1537 329–1537	COL Kingston/COL Moldenhauer USAES–DCD (573) 563–4076/(573) 563–4082 676–4076/676–4082	Brian Hornbeck TARDEC (810) 574–5608 786–5608

IV.EN.2001.01—FUTURE COMBAT SYSTEMS MINE DETECTION AND NEUTRALIZATION. FCS mounted standoff mine detection and neutralization provides the warfighter enhanced operational tempo (rates of advance) during route clearance and mine avoidance missions, increases vehicle survivability, and enhances soldier survivability. The primary objective of this program is to investigate, develop, and evaluate forward-looking sensor technologies, signal processing techniques, and mine neutralization techniques applicable to the detection and neutralization of on-/off-route surface and buried antitank

mines. The technical goals are (1) detection and location of mines 10 to 30 m in front of the host vehicle while advancing at 15–20 kph and (2) neutralization of mines 10 to 50 m away while advancing at 10–20 kph with a P_k of 90–95 percent. The system will be modular to permit bolt-on integration onto FCS vehicle platforms, avoiding the need for specialized overpass vehicles and following confirmation sensors. The program also focuses on total life-cycle costs, sustainability, and maintainability. Sensor and neutralization technology will transition to advanced development and technology insertion into 6.3 programs.

By FY01, design and build forward-looking sensors using candidate technologies; and complete initial experiments, phenomenology analysis of data collected, and modeling of forward-looking sensors, detection algorithms, and neutralization techniques (TRL 3). By FY02, build competing detection brassboard prototypes based on evaluation and assessment of modeling and prior field experiments; and perform modeling and experimentation with different point neutralization techniques (TRL 4/5). By FY03, evaluate detection prototypes and neutralization breadboard hardware, compare to exit criteria, and conduct final technology demonstration and transition criteria/designs for brassboard systems (TRL 5). By FY04, complete full integration of detection and neutralization technology on host vehicle with full operational and user involvement in a realistic environment (TRL 6).

Supports: FCS, MBBL, MSBL.

TSO	TRADOC POC	STO Manager
Rob Saunders	LTC(P) Charles Alexander	Kelly Sherbondy
SAAL–TT	DCD, USAES&C	CERDEC/NVESD
(703) 601–1546	(573 563–4076	(703) 704–2248
329–1546	676–4076	654–2248

LOGISTICS

IV.LG.1997.01—HIGH-ENERGY, COST-EFFECTIVE PRIMARY AND RECHARGEABLE BATTERIES. This STO modifies commercial, cost-effective technologies leading to advanced high-energy batteries and hybrid power sources for use in training and combat.

In FY99, produced a low-cost, pseudo-rechargeable, environmentally benign battery (less than $0.05/watt-hour (Wh)) for use in training and low-rate applications, and improved materials and fabrication techniques for electrochemical capacitors for hybrid power sources. In FY00, provided prototypes for field trials of long-cycle-life rechargeable batteries both for training and special operations missions with a 20 percent increase in energy content, and evaluated proof-of-principle electrochemical capacitors for hybrid digital pulse C^4I applications. By FY01, demonstrate proof-of-principle prototypes of the most cost-effective, high-performance primary battery with greater than 300 Wh/kg, and optimize and scale up prototype electrochemical capacitors for higher voltage, higher power vehicle hybrid applications. By FY02, provide a prototype battery with energy density greater than 300 Wh/kg, and an electrochemical capacitor with 10X power density and 2–4X energy density integrated into a hybrid power source for field testing in digital pulse C^4I and in high-power vehicle applications that lasts more than 3X the battery alone in the same envelope. The goals will be to reduce manufacturing costs while maximizing performance and safety.

Supports: PEO–C^3S, PM–TRCS, PM–Soldier, SBCCOM, DBBL, PEO–IEW&S, Space and Missile Defense Command, Objective Force Soldier as a System.

TSO	TRADOC POC	STO Manager
Rob Saunders	Chris Cigal	Michael Brundage
SAAL–TT	CSSBL	CERDEC/C2SID
(703) 601–1546	(804) 734–0040	(732) 427–3450
329–1546	687–0040	987–3450

IV.LG.2000.01—INTEGRATED POWER GENERATION AND MANAGEMENT TECHNOLOGIES. This STO addresses critical needs in the growing warfighter power demands that are being driven by reliance on electronics through digitization and agility requirements for the Objective Force. The intent is to plan, organize, and control energy-efficient technologies and techniques across all elements of Army power: sources, storage, distribution and consumption.

In FY00, demonstrated smart hybrid battery/electrochemical capacitors using components from leveraged programs, assessed KE component technologies, developed generator power electronics scalability, and selected and evolved a tool applicable for efficient Army electronics systems design. By the end of FY01, optimize battery capacitor hybrid size, weight and cost; transition DARPA TPV results to CECOM; design and build kinetic prototypes; demonstrate optimized electromechanical technology on a 5-kW testbed; and evolve tool for system-level, low-power design. By the end of FY 02, deliver hybrid and kinetic prototypes for field trials (TRL 4), design and develop 500-W thermophotovoltaic power system (TRL 4), demonstrate power-on-the-move, and demonstrate application of low-power design tool to test LW for reduced power consumption (TRL 4).

Supports: PM–Soldier, PM–Mobile Electric Power.

TSO	TRADOC POC	STO Manager
Robert Saunders	Charles Holmes	Maureen Molz
SAAL–TT	CASCOM	CERDEC/C2SID
(703) 601–1546	(804) 734–0036	(732) 427–3149
329–1546	687–0036	987–3149

IV.LG.2000.02—ADVANCED TACTICAL FUELS AND LUBRICANTS. The focus of this STO is to develop enhanced and alternative fuels with higher thermal stability, higher energy (6–15 percent), extended storage, and onboard smoke production (e.g.,vehicle engine exhaust smoke); and enhanced and alternative lubricants that will reduce frictional losses, have extended operational capabilities, and be environmentally responsive. These enhanced/alternative products will impart benefits across all ground vehicle systems and platforms to provide for higher fuel economy (2–8 percent), less refueling and scheduled maintenance stops, higher engine temperature operation, reduced scheduled maintenance and labor, and a reduced logistic tail. Future Army ground vehicles, aviation aircraft, and other systems envisioned in future designs all have increased oil temperatures, higher load to oil/fuels, and more sophisticated components in engine and powertrain systems susceptible to F&L effects. The advanced fuels will have an enhanced energy content of 6–15 percent that will increase the range and operability of vehicles, aircraft, and equipment or reduce weight while maintaining the same range. The new advanced lube products must provide extended operation, reduce frictional losses, operate under higher operating temperatures, and not contribute to emission pollutants. The advanced products will reduce maintenance costs by 25 percent, require less lubricant during the life of the equipment and less man-hours to maintain vehicles; and increase fuel economy by 4 percent.

In FY00, identified fuels and fuel products with enhanced energy content as well as processes with potential for producing fuels with enhanced energy content and alternative sources and lubricants with enhanced and alternative characteristics. In FY01, obtain samples for evaluation of physical properties. By the end of FY02, develop a bench test to assess enhanced lubricants and evaluate combination of fuel products to determine if further increases in energy or performance can be obtained. In FY03, conduct field evaluation of new products to quantify enhancements and transition to DLA by the beginning of FY04.

Supports: FCS, Legacy systems and support equipment.

TSO	TRADOC POC	STO Manager
John Appel	William Purdue	Luis Villahermosa
SAAL–TT	CASCOM	TACOM–TARDEC
(703) 601–1537	(804) 734–1945	(810) 574–4207
329–1537	687–1945	786–4207

IV.LG.2000.03—PETROLEUM, OIL, AND LUBRICANTS (POL) QUALITY ANALYZER AND SENSORS. This program will investigate miniaturized, portable petroleum analysis technologies. One such technology may be a handheld device capable of sampling and analyzing petroleum from a variety of sources, including fuels and hydraulic, transmission, or engine oil. Another potentially viable instrument is a vehicle-mounted sensor for analyzing used oil to determine its condition and alert personnel to imminent maintenance requirements. This capability has the potential to decrease cost and time of sampling and analyzing fuel or oil samples. The decreased turnaround time for sample analysis will provide several benefits. For example, force mobility will increase as unit commanders will be able to know immediately if captured fuels are usable; and knowledge of oil and engine condition will enable critical decisionmaking based on need for specific maintenance.

In FY00, selected the most critical oil analysis parameters and key technologies. In FY01, perform laboratory confirmation of key technologies and evaluate methods of integrating these into the current system. In FY02, test device integration into system for one online or handheld unit. In FY03, develop software to download sensor data to the current Army Oil Analysis Program database. In FY04. field handheld units or mount sensors on a fleet of vehicles.

Supports: FCS, Legacy systems and support equipment.

TSO	**TRADOC POC**	**STO Manager**
John Appel	William Purdue	Steve Moyer
SAAL–TT	CASCOM	TACOM–TARDEC
(703) 601–1537	(804) 734–1945	(810) 574–4206
329–1537	687–1945	786–4206

IV.LG.2000.04—WATER PURIFICATION TECHNOLOGY. The focus of this STO is the research, development, and testing of innovative individual or small-unit water production, purification, and desalination systems that reduce the water support logistics footprint of Army XXI, its enhancements, and the Objective Force. It will transition advanced water purification, desalination, and production technologies, investigated by the DARPA Mesomachine Program and the SBIR Program. These technologies will be integrated into operational systems that meet the stringent requirements for individual, small-unit, and medical unit water supply. The program will validate the product water quality and production rate, as well as the system size, weight, durability, and power requirements, through comprehensive testing to assess producibility and affordability.

By FY01, evaluate alternative concepts transitioned from DARPA and select those technologies ready to transition into breadboard prototypes (TRL 4). By FY02, complete comprehensive testing of the prototypes, identifying those which can produce 100 percent of a soldier's daily drinking water requirements, which will reduce the demand on the already overloaded logistical system (TRL 6). By FY03, demonstrate a system that reduces the weight of water or water-producing equipment that must be transported by 25 percent, thus supporting the goal of reducing the load carried by the individual (TRL 6). By the end of FY04, complete operational testing of a water production system that meets all the above requirements while reducing the operating (or price per gallon) costs by 20 percent (TRL 7). Validate the ability of Army water systems to remove contaminants identified by the Army Medical Department (AMEDD) to ensure soldier safety.

Supports: FCS, dismounted soldiers, Objective Force.

TSO	TRADOC POC	STO Manager
John Appel	Jon Walker	Bob Shalewitz/Jay Dusenbury
SAAL–TT	CASCOM	TACOM–TARDEC
(703) 601–1537	(804) 734–0613	(810) 574–4128
329–1537	687–0613	786–4128

IV.LG.2000.05—REMOTE READINESS ASSET PROGNOSTICS/DIAGNOSTICS SYSTEM (RRAPDS). This STO is a joint effort between the Aviation and Missile Command–Aviation and Missile Research, Development and Engineering Center (AMCOM–AMRDEC) and TACOM–ARDEC. RRAPDS will provide an integrated system transparent to the warfighter that remotely monitors the environments experienced by missiles and munitions to determine out-of-spec conditions and to quantify remaining useful life in plastic encapsulated microcircuits (PEMs), solder joints, and propellants while assets are tactically deployed, in storage, or being transported. RRAPDS advancements in condition monitoring technology contribute to the *Revolution in Military Logistics*, whereby the Army will reap enormous benefits in streamlined maintenance, efficient supply, lower operating and support costs, and assured effectiveness.

In FY00, designed and fabricated a basic on-weapon MEMS-based environmental sensor suite. By the end FY01, develop a digital system manager, integrate it with the sensor suite to optimize power consumption, and finalize and validate limited failure models. By the end of FY02, integrate and demonstrate a "full-up" system sized for the TOW missile upgrade, and demonstrate RRAPDS as an HTI candidate for a launch platform and a high-value conventional munition (TRL 4).

TSO	TRADOC POC	STO Manager
Mary Miller	William Moore	Wyatt Shankle
SAAL–TT	USA Combined Arms Support Command	AMCOM AMRDEC
(703) 601–1543	(804) 734–1891	(256) 876–3250
329–1543	687–1891	746–3250

IV.LG.2001.01—POWER CONVERSION TECHNOLOGY FOR FUTURE COMBAT SYSTEMS. This effort enhances deployability of FCS by reducing the weight and volume requirements for power conditioning and conversion systems that are required by all electrical loads. It is an enabling technology for hybrid/electric drive capability, which greatly improves fuel efficiency and thereby reduces the logistics footprint of the future objective forces. Circuit topologies will be investigated, including the matrix converter, which eliminates large and heavy dc link components (capacitors and inductors) to significantly reduce converter size by 60–75 percent and weight by 50 percent. The matrix converter also can be configured as an ac-ac, dc-ac, ac-dc, or dc-dc converter. It has power factor control, which improves efficiency and boosts fuel economy. These converters will use silicon or advanced high-temperature (300°C) voltage-controlled silicon carbide (SiC) switches. The use of SiC switches will further decrease the size and weight of the power conditioning and conversion system by eliminating or reducing the need for a low-temperature cooling system.

By FY01, demonstrate a 10-kW low-temperature matrix converter at TRL 5. By FY02, demonstrate a 100-kW low-temperature matrix converter at TRL 4. By FY03, demonstrate a 100-kW low-temperature matrix converter at TRL 5. By FY04, demonstrate a 10-kW high-temperature matrix converter at TRL 5

Supports: FCS.

TSO	TRADOC POC	STO Manager
Cathy Kominos	COL Henry Hughes	Major Jim Raftery
SAAL–TR	USAAC	ARL-SEDD
(703) 601-1524	(502) 624-5050	(301) 394-5200
329–1524	464–5050	290–5200

MATERIALS, MATERIAL PROCESSES, AND STRUCTURES

IV.MA.1998.01—CANNON WEAR AND EROSION. The focus of this STO is to demonstrate the viability of wear- and erosion-resistant coatings that are applicable to both medium- and large-caliber gun barrels to improve gun barrel life by tenfold compared with current equivalent gun barrels when used with advanced or higher energy propellants or munitions. The STO will deliver a gun barrel erosion modeling package in which the gun system parameters are input. Results will include wall material removal rates, surface coating removal rates, and locations. A user will be able to "predict" how erosive a proposed system may be, alone or in comparison with known systems, given changes in propellant chemistry, surface coating, or bulk gun material. The package will include equilibrium and finite-rate chemistry modules with the user supplying the inputs for the desired thermochemistry, reactions, and rates. It will also provide a field-retrofittable obturator design for direct retrofit to 155-mm projectiles currently in the inventory intended for use with Crusader Zone 6 charges.

In FY99, determined coating candidates and fabricated coating coupons for testing, began development of the alternative high-velocity oxygen fuel (HVOF) coating process with an evaluation of various coating materials, started work on a gun barrel modeling package, and initiated design and development of a retrofittable projectile obturator for the inventory of projectiles intended for use with Crusader Zone 6 charges (TRL 4). In FY00, conducted and evaluated coating coupon testing for both the lead and alternative coating approach (TRL 5). In FY01, test the lead coating/process combination on a medium-caliber barrel, apply the alternative HVOF technique to a large-caliber barrel section, finalize the gun barrel erosion modeling package, and finalize the design and development of a retrofittable obturator for the inventory of projectiles intended for use with Crusader Zone 6 charges (TRL 5/6).

Supports: 25-, 120-, and 155-mm ammunition and cannon systems, FCS Multirole ETC Armament System.

TSO	TRADOC POC	STO Manager
John Appel	A. Winkenhofer	Michael Audino
SAAL–TT	USAARMC	ARDEC
(703) 601–1537	(502) 624–8064	(518) 266–5740
329–1537	464–8064	974–5740

IV.MA.1999.01—A NOVEL, LOW-COST, COMPOSITE ARMOR AND ARMY VEHICLE MATERIEL MANUFACTURING PROCESS. Next-generation ground vehicle, helicopter, and LOC bridge infrastructure demands both low-cost and superior performing composites. This STO capitalizes on a novel composite processing technology specifically designed in response to these requirements.

In FY99, developed working prototype of process. In FY00, fabricated multifunctional armor with process. By FY01, demonstrate process on thick-section ground vehicle and LOC bridge materiel. By FY02, apply to thin-shell helicopter materiel. The process, "Vmax," will improve mechanical and ballistic properties 10–30 percent while achieving a 20–50 percent cost reduction over conventional autoclave processes. Vmax will revolutionize the affordable manufacture of DoD/NASA composite materiel, and thereby remove economic barriers currently preventing further use of composite systems and components.

Supports: PM–Crusader, PM–Comanche, LOC Bridges.

TSO	TRADOC POC	STO Manager
Cathy Kominos	Martin Bosemer	Shawn Walsh
SAAL–TR	Armor Center & School	ARL–WMR
(703) 601–1524	(502) 624–2045	(410) 306–0815
329–1524	464–2045	458–0815

IV.MA.2001.01—METAL MATRIX COMPOSITES (MMCs) FOR ORDNANCE APPLICATIONS. This program adapts continuous fiber MMC technology from the commercial sector to enable a 50 percent weight reduction of future projectiles/armaments.

During FY01, validate engineering properties (thermal and mechanical) and develop modeling capabilities for continuous-alumina, fiber-reinforced aluminum (TRL 3). At the end of FY01, identify one application (either a lightweight projectile shell or lightweight barrel component) for developing a prototype for this technology (TRL 3). During FY02, develop specific technologies for this application (joining technologies, nondestructive evaluation, and appropriate building block tests) (TRL 4). During FY03, demonstrate this capability through fabrication and testing of a full-scale prototype. The prototype will be either a projectile shell 50 percent lighter than steel shells (with 67 percent less parasitic volume than polymer matrix composite shells) or barrel components 50 percent lighter than existing systems (TRL 5).

Supports: FCS Technology Demonstrator.

TSO	TRADOC POC	STO Manager
Cathy Kominos	COL George Svitak	John Beatty
SAAL–TR	DCD Artillery Center	ARL-WMRD
(703) 601–1524	(580) 442-6980	(410) 306–0869
329–1524	639–6980	458–0869

SENSORS AND ELECTRONICS

IV.SN.1996.01—ADVANCED FOCAL PLANE ARRAY (FPA) TECHNOLOGY. This STO focuses on the development and maturation of components for a more advanced generation of IR imaging sensors, which take advantage of advanced, large-staring FOAs that allow smart temporal and multispectral signal processing. Technology will be developed to provide affordable tactical vehicle quality imagers in the 3- to 5-μm and 8- to 12-μm bands, including practical nonuniformity correction.

In FY99, demonstrated multispectral sensing and partition smart functions between on- and off-focal plane processing. In FY00, integrated multispectral smart sensing functions that demonstrate key aspects of emerging third-generation FLIR architecture with staring FPA (TRL 4). By FY01, demonstrate large focal plane that incorporates hyperspectral, smart sensing functions based on third-generation FLIR architecture. These objectives can be obtained by integrating multispectral/hyperspectral FPAs with smart-readout integrated circuits, innovative micro-optics, and adaptive micro-/nano-electronics into tactical dewars (TRL 5).

Supports: PM–NV/RSTA, MBSBL, DBBL, D&SABL, EELSBL, BCBL.

TSO	TRADOC POC	STO Manager
Rob Saunders	Martin Bosemer	Stuart Horn
SAAL–TT	DFD, Ft. Knox	CERDEC/NVESD
(703) 601–1546	(502) 624–2045	(703) 704–2025
329–1546	464–2045	654–2025

IV.SN.1997.01—NEAR-INFRARED SENSORS. This STO develops a low-cost, lightweight, low-light-level, exclusively solid-state sensor with smart readout chip to provide a digital output and become an integral part of the future digital battlefield. This technology will provide affordable, high-resolution sensors for reflected light in the 0.4- to 1.8-μm wavelength region for systems supporting airborne, combat vehicle, and light infantry missions. This sensor technology will be immune to bright-light "flashouts" and will require no vacuum tube technology. These sensors will have high resolution and sensitivity to detect sniper fire, detect targets through conventional camouflage, detect laser rangefinders/designators, and detect stressed vegetation.

In FY99, developed a low-cost, solid-state, near-IR camera that demonstrated comparable sensitivity to present 12 tubes and can be transitioned as an HTI for all future vision devices. In FY00, developed a large-format, near-IR, solid-state FPA that can be used for sniper scope applications and pick out targets in camouflage at long ranges. By FY01, demonstrate a near-IR sensor for lightweight goggle applications (TRL 5).

Supports: PM–NV/RSTA.

TSO	TRADOC POC	STO Manager
Rob Saunders	Chris Kearns	Bill Markey
SAAL–TT	DBBL	CERDEC/NVESD
(703) 601–1546	(706) 545–6391	(703) 704–1306
329–1546	835–6391	654–1306

IV.SN.1997.02—ADVANCED SIGNATURE MANAGEMENT AND DECEPTION. This program demonstrates technologies that enable development of signature management systems (SMSs) and deception systems that deny acquisition of friendly force assets from threat sensors. Demonstrations will be supported by signature characterization M&S conducted under the Integrated Sensor modeling and simulation effort. These SMSs and deception systems provide mobile and semimobile assets with low-cost, low-operational burden survivability upgrades addressing detection avoidance in global battlefield conditions.

In FY99, developed reactive IR suppressive coatings, appliques, and structures to reduce vehicle and solar loading signatures over an extended period of a diurnal cycle and in varying backgrounds; and completed feasibility study for battlefield deception technologies. In FY00, developed a hybrid SMS to reduce the detection range of tactical, mine warfare, and fire support vehicles by 50 percent; and developed the Ultra-Lightweight Camouflage Net System screen, which significantly reduces the signature of general-purpose platforms in a desert/urban environment. By FY01, demonstrate synergistic coupling of physical and virtual decoys with passive and active signature management to improve survivability of combat and combat support units. By FY02, develop a multispectral SMS and deception system operating in the radar, IR, and visual spectrums for tactical, mine warfare, fire support, and combat vehicles (TRL 4/5).

Supports: Objective Force systems.

TSO	TRADOC POC	STO Manager
Rob Saunders	Martin Bosemer	Rob Adams
SAAL–TT	DFD, Ft. Knox	CERDEC/NVESD
(703) 601–1546	(503) 624–2045	(703) 704–2583
329–1546	464–2045	654–2583

IV.SN.1997.03—INTEGRATED SENSOR MODELING AND SIMULATION. This program advances the state-of-the-art in synergistic modeling and prototyping capabilities to permit end-to-end predictive modeling and hardware tradeoffs for performance evaluation of new technologies in a virtual environment. Implementation will be supported by development of high-resolution, 3D target, background, and clutter object databases that will scale from dismounted infantry to airborne applications. Features will also include realistic portrayal of advanced sensors such as third-generation FLIRs, acoustics, and radars; aided, automatic, and fused sensor usage; LO signature management techniques; and mine targets. Linked or inserted into operational simulations, this technology will allow warfighters to test new capabilities, develop tactics and techniques, evaluate operational effectiveness, plan missions, and train in parallel with the hardware development process.

In FY99, developed real-time multispectral (0.4 to 14 μm) capability for insertion into wargame simulations. In FY00, developed and integrated SAR and MMW capability for insertion into wargame simulations. By FY01, validate multispectral portrayal for search and target acquisition simulations and implementation for driving and pilotage simulations.

Supports: FCS, Objective Force.

TSO	TRADOC POC	STO Manager
Rob Saunders	David Estes	Bill Jarvis
SAAL–TT	MMBL	CERDEC/NVESD
(703) 601–1546	(502) 624–4989	(703) 704–1236
329–1546	464–4989	654–1236

IV.SN.1998.01—MICRO-EYESAFE, SOLID-STATE LASER SOURCES. Low-cost, lightweight lasers will benefit the warfighter for multiple applications, including microrangefinders, combat identification systems, training, and target pointers for individual soldiers as well as compact devices for infrared countermeasures and munitions. The development of "micro," low-cost laser devices will complement the larger multifunction lasers under development for mounted applications. Recent improvements in nonlinear materials and laser diodes have made it feasible to develop microlaser devices that can produce wavelengths from the ultraviolet to the far infrared to meet the requirements for precision weapons, lightweight mid-IR/far-IR sources for IRCM, and laser radar for munitions. Examples of lasers to be developed are high-peak-power, eyesafe, laser diodes; microdiode-pumped lasers shifted with periodically poled lithium niobate optical parametric oscillators; and far-IR semiconductor laser sources.

In FY00, demonstrated candidate low-cost laser devices and characterize performance. By FY01, develop candidate devices in ultra-compact form for applications. By FY02, demonstrate sensors and systems based on the laser devices and evaluate performance (TRL 5).

Supports: DBBL, MBSBL, LW, PM–AES, PM–NV/RSTA.

TSO	TRADOC POC	STO Manager
Rob Saunders	Chris Kearns	Ward Trussel
SAAL–TT	DBBL	CERDEC/NVESD
(703) 601–1546	(706) 545–6391	(703) 704–1355
329–1546	835–6391	654–1355

IV.SN.1998.02—LOW-COST, ELECTRONICALLY SCANNED ANTENNA (ESA). The focus of this STO is to develop and demonstrate a set of cost-effective technologies for ESAs that can be used for multiple Army platforms and applications. An advantage of ESA technology in a cost-effective package is to have the ability to control an aperture beam quickly. This will enable multimode operations where radar surveillance, target acquisition, fire control, CID, electronic intelligence, and communications are performed within one integrated system. The principal benefit of this technology is that it provides simultaneous multimode and enhanced radar system performance with increased lethality and survivability of Army assets.

In FY98, demonstrated a Ku-band Rotman lens with Vivaldi notch aperture and single-beam switching matrix for technical performance. In FY99, characterized Ka-band Rotman lens with a 34-element linear horn array for <3-degree azimuth beamwidth. In FY00, evaluated and selected a switch technology for

multibeam generation capability, which will lead to a crossbar switch. By FY01, demonstrate low-cost, crossbar beam switching architectures (e.g., MEMS switches) for multibeam demonstration with Ku-band Rotman lens.

Supports: MTI ground radar, UAV radar, Longbow, CERDEC.

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos	MAJ David A. Tippett	Edward Burke
SAAL–TR	Depth & Simultaneous Attack	ARL–SED
(703) 601–1524	(580) 422-3139	(301) 394–4375
329–1524	639–3139	290–4375

IV.SN.1999.01—THIRD-GENERATION INFRARED IMAGING TECHNOLOGY. The focus of this joint CECOM/ARL program is to develop FPA technology for the next-generation FLIR sensors. The components developed will show improved performance—well beyond the capability of the current single-wavelength, second-generation FLIR technology—through better recognition ability, faster decision times, and higher operating temperature; and be better able to function in all battlefield environments. The new sensor will all but eliminate the ability of threats to hide or employ countermeasures. This will be accomplished by adding multiple wavelengths of passive detection, as well as an active component (LADAR) for target ID. Advanced smart, readout circuits and signal processing will be embedded that take advantage of the enhanced information and aid the viewer in decisionmaking regarding target detection, identification, and battle damage assessment. The passive sensors will have large arrays for increased resolution, multiple wavelengths for better identification in all battlefield conditions, and hyperspectral and polarization readout capabilities to improve LO target ID range over the current FLIR. The active sensor will use an eyesafe laser, produce target information in real time, and add certainty to the ID process. The overall cost of the new sensor should be comparable to that of the second-generation FLIR.

In FY00, demonstrated the feasibility of multispectral detector arrays grown directly on silicon. By FY01, demonstrate a large-area (480x640 and 1000x1000), dual-color (MWIR/LWIR) FPA with optical interconnects and eyesafe LADAR. By FY02, demonstrate laser rangefinding and target profiling on the same array. By FY03, demonstrate an integrated, multicolor, large-area (1000x2000) FPA with parallel, optical readouts, active LADAR, and 120 K operating temperature.

Supports: Future battlespace visualization involving Army thermal-imaging systems in tanks, helicopters, missiles, and autonomous scout vehicles; MMBL, DBBL, D&SABL, SP.

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos	Martin Bosemer	Dr. William Clark III
SAAL–TR	DFD, Ft. Knox	ARL–SED
(703) 601–1524	(502) 624–2045	(301) 394–4617
329–1524	464–2045	290–4617

IV.SN.1999.02—WARRIOR EXTENDED BATTLESPACE SENSORS (WEBS). The focus of this joint ARL/CECOM effort is to develop a family of affordable, ubiquitous sensors to enhance the cognitive performance of the Objective Force warfighter. WEBS will provide a revolutionary increase in battlespace awareness that will improve individual soldier survivability and lethality, and enable commanders and staffs to plan, decide, and execute operations at Objective Force speeds and tempos. Proliferation of the technology will address physical and cognitive performance limitations across multiple levels of users, from the individual warrior through small or special forces units to the tactical ground force commander. The products will be a family of microminiature sensors using acoustic, seismic, IR, magnetic, RF, and inertial measurement technologies that provide equivalent capabilities to Platoon Early Warning Device II and the Improved Remotely Monitored Battlefield Sensor System, with several orders of magnitude improvement in size, weight, and power. The sensors will be employed on the warfighter, in distributed networks, on manned and unmanned vehicles (including microrobotic vehicles), and in munitions. Applications will allow low-cost, low-burden forward- and rear-area surveillance, alerting, and denial, and continuous monitoring of troop/vehicle movements and munitions activity in all battlefield environments. Further applications of WEBS include embedded diagnostics and health/human performance monitoring.

In FY99, demonstrated an integrated network of acoustic and seismic microsensors. In FY00, developed local network communications protocols and demonstrated visible imaging microsensor and IR imaging microsensor designs. By FY01, demonstrate a small-scale integrated network of acoustic, seismic, and imaging microsensors. By FY02, demonstrate microinertial navigation systems for the individual soldier or robotics platforms, and integrated network of acoustic, seismic, and IR imaging microsensors capable of unattended operation for 120 days. By FY03, demonstrate an integrated network concept of acoustic, seismic, and IR imaging microsensors with package sizes less than 1 cubic inch that are potentially munitions deployable (TRL 5).

Supports: FCS, Objective Force Soldier System, Antipersonnel Landmine Alternatives.

TSO	TRADOC POC	STO Manager
Rob Saunders	Chris Kearns	Jim Brown
SAAL–TT	DBBL	CERDEC/NVESD
(703) 601–1546	(706) 545–6391	(703) 704–3064
329–1546	835–6391	654–3064

IV.SN.1999.03—LOW-POWER DISPLAY COMPONENTS. This program reduces power consumption by >50 percent over existing HMDs, enabling the warfighter to execute longer missions with less head-borne weight and logistics burden. The technology products will be miniature flat-panel displays that consume less power, save weight and space, support both monochrome and full-color applications, have high-image fidelity, and integrate easily with current and next-generation sensors.

In FY00, demonstrated monochrome 1280x1024 display (8 bit, 0.75 W/75 fL with associated drive electronics) and transitioned monochrome 640x512 display (8 bit, 0.5 W/75 fL) to the Low-Power Uncooled IR Sensor Demonstration. By FY01, develop 640x512 display (red/green/blue color, 1.0 W/25 fL) and monochrome 1920x1080 display (8 bit, 1W/75 fL) for transition to the Mounted Warrior program. By FY02, initiate development of reduced-power, high-brightness monochrome 1280x1024 and 1920x1080 (1500 fL) displays for see-through applications. By FY03, demonstrate high-brightness display compo-

nents for see-through applications, and complete development of ambient optical-channel attenuators and color optics to enhance display performance. Demonstrate manufacturing base capability to meet military display needs. Develop and transition a Standard Advanced Dewar Assembly II scan convertor to the Mounted Warrior program.

Supports: PM–NV/RSTA.

TSO	**TRADOC POC**	**STO Manager**
Rob Saunders	Chris Kearns	Colin Reese
SAAL–TT	DBBL	CERDEC/NVESD
(703) 601–1546	(706) 545–6391	(703) 704–1309
329–1546	835–6391	654–1309

IV.SN.2000.01—ADVANCED ACOUSTIC/SEISMIC SYSTEMS. This STO has three primary objectives: (1) demonstrate acoustic sensor systems that can accurately locate (with target location error <120 m) enemy artillery mortar and cannon fires; (2) develop an integrated acoustic/seismic modeling capability, including tactical decision aids; and (3) demonstrate a network architecture of a randomly dispersed, low-cost acoustic sensor field, including remote deployment techniques such as artillery delivery and ATACMS.

In FY00, developed an effective windscreen and vehicle self-noise cancellation algorithm/software for Strikers (HMMWV platform); and developed acoustic/seismic propagation models and related performance to potential gains in cost and operational effectiveness of a sensor network. In FY01, collect signatures on mortars and add data to expand detection capability; demonstrate modeling and target location and tracking capabilities against non-real-time data, and assess improvements in operational effectiveness; and initiate development of advanced detection, classification, and tracking algorithms. In FY02, demonstrate integrated acoustic cuers on Strikers for AN/TPQ–36/37 and transmit detection messages to the fire director center; incorporate advanced detection, classification, and tracking algorithms and software into acoustic sensor testbeds (e.g., Integrated Acoustic System (IAS), Remote Sentry, Improved Remotely Monitored Battlefield Sensor System (IREMBASS), Raptor, and Wide Area Mine (WAM) hardware) and validate the modeling predictions with sensor improvements; and develop network architecture for low-cost sensor fields. In FY 03, refine integrated acoustic/seismic modeling, develop critical components for artillery-deliverable hardened sensors, and develop multiple, networked sensors using IAS, Remote Sentry, Raptor, IREMBASS, and WAM hardware. In FY04, demonstrate networked acoustic sensors and critical components of artillery-deliverable hardened sensors.

Supports: FCS, PM–Mines.

TSO	**TRADOC POC**	**STO Manager**
John Appel	George Durham	Jeffrey Heberley
SAAL–TT	D&SABL	ARDEC
(703) 601–1537	(580) 442–6383	(973) 724–6255
329-1537	639–6383	880–6255

IV.SN.2000.02—SENSOR OPTOELECTRONIC PROCESSING. The focus of this STO is to develop optoelectronic (OE) interconnect technologies and architectures for future Army sensors such as hyperspectral imagers and foliage-penetrating radar. Although electronic processing capabilities are advancing rapidly, they will be outstripped by the high-speed, high-volume data processing requirements of Army sensors on future battlefield platforms. Parallel OE interconnects should increase data rates up to and beyond 1 Tb/s, reduce power consumption to below 10 nW/mm^2 for each operation per second, and thereby enable rapid dissemination of information.

By FY01, demonstrate high-data-rate image transfer with electronic processing (e.g., vertical-edge detection, via integration of electronics and optoelectronics). By FY02, demonstrate high-data-rate, parallel image processing (e.g., edge detection and image filtering; optical fan-out and electronic processing). By FY03, demonstrate high-data-rate image processing (e.g., image half-toning with USMA or SAR processing with AMCOM and Sanders; optical fan-out and optical fan-in via integration of electronics, optoelectronics, and passive optics). By FY04, demonstrate an OE processor that is scalable to a high-performance smart sensor (e.g., foliage-penetrating SAR, IR, and visible hyperspectral imaging).

Supports: Objective Force reconnaissance, surveillance, target acquisition, IFF, and counter-low-observable systems, including hyperspectral imagers, foliage-penetrating SAR, and smart munitions under development at AMCOM and CECOM

TSO	**TRADOC POC**	**STO Manager**
Cathy Kominos	COL Charles Atkins	George Simonis
SAAL–TR	INTEL DCD	ARL-SED
(703) 601–1524	(520) 533-2413	(301) 394–5754
329–1524	821–2413	290–5754

IV.SN.2000.03—MULTIFUNCTION RADIO FREQUENCY SENSOR TECHNOLOGY. The focus of this STO is to bring high-performance sensor functionality (Longbow-like fire control) to the low-cost, lightweight ground vehicles of the future. To accomplish this goal, this program will develop and demonstrate the technologies required to integrate multifunction RF capability into systems so that simultaneous target acquisition, combat identification, and communications can be performed by the same sensor. The principal benefit of this technology is that it provides simultaneous multimode and enhanced radar system performance with increased lethality and survivability of Army assets, thereby reducing the number, complexity, and logistics support requirements of future Army systems.

In FY00, demonstrated communication and target acquisition waveforms in a common Ka-band antenna, and analyzed the component requirements for implementing a multifunction capability. In FY01, develop and integrate the components required to demonstrate a Ka-band vertically scanned active E-scan antenna array that will be added to the 1D E-scan antenna from an existing STO. In FY02, demonstrate a 2D Ka-band E-scan antenna system and determine waveform requirements for weapon guidance and combat ID. In FY03, demonstrate a multifunction RF system performing target acquisition and communication simultaneously using the 2D Ka-band E-scan antenna.

Supports: MTI ground radar, UAV radar, CERDEC.

TSO	TRADOC POC	STO Manager
Cathy Kominos	Martin Bosemer	Ronald Wellman
SAAL–TR	DFD, Ft. Knox	ARL-SED
(703) 601–1524	(502) 624–2045	(301) 394–3171
329–1524	464–2045	290–3171

IV.SN.2000.04—SPECTRAL/SPATIAL DATA EXPLOITATION FOR TERRAIN CATEGORIZATION AND TARGET IDENTIFICATION. This program implements spectral and spatial exploitation technologies that operate on multispectral and hyperspectral imagery to support integrated terrain categorization and target identification. The goal is to support military operations in a practical manner by implementing those technologies that degrade gracefully in nonoptimal force deployment situations. Technologies that exploit various regions of the electromagnetic spectrum will be investigated and implemented, as appropriate, including the visible through LWIR wavelengths of light. Spatial information inherent in the primary image source is used, along with spectral and spatial information from secondary sources whenever available.

By FY02, demonstrate 2X improvement in false target discrimination over current single-band approaches for targets in the clear with light to moderate clutter, and 2X reduction in terrain misclassifications for four classes of terrain. By FY04, demonstrate 5X improvement in false target discrimination over current single-band approaches in light clutter; 0.2X improvement in target detection performance for highly obscured (50%) targets; and 2X improvement in terrain classification performance (i.e., half as many misclassifications) for 10 classes of terrain.

Supports: FOCs: TR 97–21, Real-Time Target Acquisition; TR 97–003, Mission Planning and Rehearsal.

TSO	TRADOC POC	STO Manager
Jeff Messmore	Brian Murphy	Constance Gray
SAAL–TR	MANSCEN Terrain Vis Ctr	CEERD-TR-S
(703) 601–1523	(573) 596-0131 x3-5332	(703) 428–6735
329–1523	581–0131	328–6735

BATTLESPACE ENVIRONMENT

IV.BA.1997.01—WEATHER IMPACTS AND DECISION AIDS (WIDA) FOR MISSION REHEARSAL, TRAINING, AND BATTLEFIELD EXECUTION. This STO improves battlefield WIDA so that Integrated Meteorological System (IMETS) forecast weather and predicted impacts on systems and operations are usable in mission rehearsal, training, and combat simulations, thus allowing forces to "train as we fight." The program will quantify weather impacts to improve current qualitative "red-yellow-green" stoplight outputs from integrated weather effects decision aids (IWEDA), developed for the fielded IMETS and Army Battle Command System (ABCS).

In FY98, extended IWEDA qualitative, rule-based warnings and impacts to use more quantitative atmospheric effects and system performance. In FY99, incorporated quantified impacts of acoustics, illumination, propagation, smoke obscuration, terrain-coupled wind transport, and weather forecasts. In FY00, extended weather impact decision aids to 4D weather impacts with improved forecast battlescale weather and atmospheric effects on weapon systems and operations. By FY01, upgrade characteristics and weather impacts on threat systems. By FY02, integrate improvements into IMETS to upgrade tactical ABCS weather-impacts and decision aids. Demonstrate the technology during Division XXI AWE, Corps Task Force, and follow-on AWEs, incorporating real-time own-the-weather capability for Force XXI situation awareness, mission planning, and combat training.

Supports: PD–IMETS, Force XXI AWEs, IEW Technology Investment Strategy, Army First Digitized Division.

TSO	TRADOC POC	STO Manager
Cathy Kominos	CPT Natalie Finley	Don Hoock
SAAL–TR	BCBL	ARL, AMSRL-IS-EW
(703) 601–1524	(913) 684–2359	(505) 678–5430
329–1524	522–2359	258–5430

IV.BA.1997.02—WEATHER EFFECTS AND BATTLESCALE FORECASTS FOR COMBAT SIMULATION AND TRAINING. This STO integrates improved battlescale forecasting, real-time weather, and environmental effects models to provide common, unified weather effects, features, and representations for Force XXI AWEs, the IEW Technology Investment Strategy, TRADOC combat models and distributed simulations (e.g., the Synthetic Theater of War Campaign Plan), and Brigade Task Force XXI mission rehearsal.

In FY97, within the IEW common operating environment, extended the Battlescale Forecast Model to provide weather forecast data for distributed interactive simulations (DIS) (TRL 3). In FY98, implemented advanced algorithms for acoustic propagation, illumination and visibility, terrain-coupled transport/diffusion and EO propagation effects at multiple levels of fidelity for environmental representations, integrated weather effects decision aids (IWEDA), and battlefield visualization tools to support simulation synthetic environments and Division XXI mission planning (TRL 4). In FY99, incorporated an Improved Battlescale Forecast Model for forecast representations of clouds, fog, severe weather (rain), and improved battlefield aerosol diffusion at tactical scales (TRL 4). By FY00, assessed improvements provided by shared battlescale weather forecasts, distributed weather processing for modeling and simulation, and physics-based atmospheric feature and effects models (TRL 5). By FY01, demonstrate interoperability of verified/validated Unified Battlescale Weather and Battlescale Atmospheric

Effects Models as a real-time own-the-weather capability for Force XXI situation awareness, mission planning, and training (TRL 6).

Supports: PD-IMETS, Force XXI AWEs, IEW Technology Investment Strategy, Army First Digitized Division.

TSO	TRADOC POC	STO Manager
Cathy Kominos	CPT Natalie Finley	Don Hoock
SAAL–TR	BCBL	ARL–ISTD
(703) 601–1524	(913) 684–2359	(505) 678–5430
329–1524	522–2359	258–5430

IV.BA.1998.01—ADVANCED GEOSPATIAL MANAGEMENT FOR INFORMATION INTEGRATION AND DISSEMINATION (AGMIID). This program develops and demonstrates an automated geospatial data management capability based on feature/attribute linking, thereby supporting the dissemination and integration of geospatial data and information at distributed user locations. AGMIID will demonstrate technology to manage increasingly complex features (point, line, then area) and functionality over the period of the program.

In FY98, initiated the standards process for defining a link structure for all feature types, completed development of point data linking, and began line data linking capability. In FY99, completed the initial standards and definition process; demonstrated linear feature linking; demonstrated the management, dissemination, and integration of point data and information; and initiated point and line linear feature management development. In FY00, demonstrated areal feature linking, completed the linear feature management development, and demonstrated the management, dissemination, and integration of point/linear data and information. By FY01, demonstrate and test the management, dissemination, and integration of point, linear, and areal data and information.

Supports: Combat Terrain Information Systems. FOCs: EN 97–001, Develop Digital Terrain Data; EN 97–002, Common Terrain Database Management.

TSO	TRADOC POC	STO Manager
Jeffrey Messmore	Brian Murphy	Richard Joy
SAAL–TR	MANSCEN Terrain Vis Ctr	CEERD-TF-G
(703) 601–1523	(573) 596-0131 x3-5322	(703) 428–7424
329–1523	581–0131	328–6505

IV.BA.1998.02—RAPID MAPPING TECHNOLOGY. This STO develops software and integrates it into an automated terrain information system to rapidly extract and properly attribute geospatial information of importance to Army and DoD customers from multiple sources with various resolutions, densities, and formats.

In FY99, incorporated and tested initial spectral imagery and SAR automated feature extraction capabilities. In FY00, incorporated automated feature extraction techniques from spectral, SAR, and electro-

optical sources into the Digital Stereo Photogrammetric Workstation (DSPW) software. By FY01, incorporate and test initial automated feature attribution capability based on terrain reasoning software and demonstrate the ability to manage, disseminate, and integrate point, line, and areal data under operational conditions. By FY02, incorporate initial terrain reasoning capability and demonstrate initial automated feature extraction and attribution capability on the DSPW.

Supports: Combat Terrain Information Systems. FOCs: EN 97–001, Develop Digital Terrain; EN 97–003, Portray a Common Terrain to the Force.

TSO	TRADOC POC	STO Manager
Jeff Messmore	Brian Murphy	William Clark
SAAL–TR	MANSCEN Terrain Vis Ctr	CEERD-TR-G
(703) 601–1523	(573) 596-0131, x3–5332	(703) 428–6802
329–1523	581–0131	328–6803

IV.BA.1998.03—THREE-DIMENSIONAL DYNAMIC MULTISPECTRAL SYNTHETIC SCENE VISUALIZATION. This program builds on the accomplishments of two previous STOs by demonstrating dynamic 3D multispectral (IR plus passive and active MMW) terrestrial backgrounds for synthetic environments by merging weather, modeled multispectral sensor performance, and terrain data.

In FY98, developed and improved visualization capabilities with the addition of dual-band IR and image intensifier capability, including the effects of meteorological conditions. In FY99, applied physics-based models to simulation applications, including visualization capabilities in support of weapon selection. In FY00, extended physics-based models and visualization capability to passive and active MMW. By FY01, integrate model-derived IR and MMW sensor performance overlays into 3D visualization. By FY02, implement 3D dynamic multispectral synthetic scene visualization into force-on-force simulation.

Supports: FOCs: TR 97–002, Situational Awareness; EN 97–003, Portray a Common Terrain to the Force.

TSO	TRADOC POC	STO Manager
Jeffrey Messmore	Brian Murphy	Thomas Jorgensen
SAAL–TR	MANSCEN Terrain Vis Ctr	CEERD-TR-R
(703) 601–1523	(573) 596-0131 x3-5332	(703) 428–8364
329–1523	581–0131	328–8364

IV.BA.1999.01—PROFILER DATA FUSION. The focus of this program is to eliminate entirely the need for balloons and hydrogen generators on the battlefield by developing a prototype Profiler that uses modern wind profiling radar technology, microwave radiometry, and meteorological satellites to collect and fuse data over the battlefield and target area at temporal resolutions and accuracy required for field artillery applications. This will reduce the Army O&M costs of field artillery meteorology systems by $33.32 million/year, and improve effectiveness of extended-range munitions. The goal is increased effectiveness of extended-range, indirect-fire cannon and rockets; optimum employment of deep-attack systems using smart munitions; and a balloon-free battlefield.

In FY99, assembled meteorological datasets for verification, validation, and error analysis of wind, temperature, and moisture data fusion algorithms; and completed an initial wind fusion module. In FY00, determined the viability of using GPS satellites and radar refractivity for moisture fusion, completed an initial moisture fusion module, and tested the previously developed temperature fusion module using regional datasets. In FY01, test the wind and moisture modules, complete error analysis of wind and moisture modules, and optimize and implement the modules on Profiler. In FY02, complete error analysis of wind and moisture modules, and optimize and implement them on Profiler. In FY03, complete verification, validation, and documentation of all data fusion algorithms and deliver to PM–NV/RSTA for advanced engineering development and integration into Profiler.

Supports: PM-Crusader, Paladin, SADARM, MLRS, AFATDS, ATACMS/BAT, D&SABL CEP, USAFAS AWE.

TSO	TRADOC POC	STO Manager
Cathy Kominos	Susan I. Walker	J. Cogan
SAAL–TR	FA School	ARL–IST
(703) 601–1524	(580) 442–6309	(505) 678–2094
329–1524	639–6309	258–2094

IV.BA.2000.01—DEEP-ATTACK AND INDIRECT-FIRE METEOROLOGICAL IMPROVEMENT. The focus of this STO is to apply battlescale meteorological prediction techniques and knowledge of target area meteorology to improve planning and execution of fire support missions, increase first-round hit probability of extended-range cannon/rocket ballistic systems, and prevent using high-cost, deep-attack weapon systems and smart munitions in meteorological conditions that would render them ineffective.

In FY00, quantified/verified launch, apogee, and target area meteorological accuracy using modeling and simulation; determined critical weather values for deep-attack weapon systems and smart munitions; developed beta meteorological kernel for interface with ballistic kernel for improved firing solutions; and formulated tactics, techniques, and procedures to exploit technology. In FY01, quantify/verify meteorology along trajectory accuracy, complete beta meteorological kernel to include meteorology along trajectory; develop weather-effects decision aids for use on Advanced Field Artillery Tactical Data System (AFATDS); and participate in live-fire exercises with ARDEC. In FY02, interface target area meteorological database with client weather effects decision aid on AFATDS and deliver final meteorological kernel and technical data packages to ARDEC. In FY03, finalize target area meteorology and weather effects decision aid software; deliver artillery meteorological system to AFATDS for integration; and assist ARDEC and CECOM Fire Support Software Engineering (FSSE) to implement meteorological kernel on FATDS fire control computers. In FY04, assist PM AFATDS and CECOM FSSE in implementing target area meteorology and decision aid software on AFATDS and artillery meteorological system.

Supports: PM–Crusader, Paladin, SADARM, MLRS, AFATDS, ATACMS/BAT, D&SABL CEP, USAFAS AWE.

TSO	TRADOC POC	STO Manager
Cathy Kominos	Susan I. Walker	David Knapp
SAAL–TR	FA School	ARL-IST
(703) 601–1524	(405) 442–6309	(505) 678–8148
329–1524	639–6309	258–8148

IV.BA.2000.02—RAPID GENERATION OF A COMMON SYNTHETIC BATTLESPACE FOR STRIKE FORCE. The focus of this STO is to develop common synthetic natural environment database generation processes to support mission rehearsal and training of a Common Synthetic Battlespace for Strike Force. This program will address the technology issues necessary to support mission rehearsal and networked, real-time, warfighter-in-the-loop simulations for the Army's Strike Force.

In FY00, analyzed the synthetic battlespace requirements, designed a process for development of a common synthetic battlespace, and demonstrated a prototype of the supporting infrastructure. In FY01, complete prototype infrastructure development, design an experiment to demonstrate that the infrastructure reduces development time and cost by a factor of 20 percent initially with a final goal of 50 percent, develop metrics to assess the environment development process, and develop a methodology to assess interoperability issues when networked with live systems. In FY02, complete process experiment and test metrics, and test methodology to assess interoperability of linked virtual, constructive, and live systems.

Supports: PM-CATT, PM-TRADE, PM-WARSIM, PM-ITTS, TRADOC battle labs

TSO	TRADOC POC	STO Manager
Cathy Kominos	COL Dennis Szydlowski	Robert Sottilare
SAAL–TR	MMBL	STRICOM
(703) 601–1524	(502) 464-7809	(407) 384–3654
329–1524	464–7809	970–3654

TECHNOLOGY READINESS LEVELS

TRL 1—Basic Principles Observed and Reported. Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.

TRL 2—Technology Concept or Application Formulated. Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.

TRL 3—Analytical and Experimental Critical Function or Characteristics Proof of Concept. Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.

TRL 4—Component or Breadboard Validation in Laboratory Environment. Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of ad hoc hardware in a laboratory.

TRL 5—Component or Breadboard Validation in Relevant Environment. Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include high-fidelity laboratory integration of components.

TRL 6—System/Subsystem Model or Prototype Demonstration in a Relevant Environment. Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.

TRL 7—System Prototype Demonstration in an Operational Environment. Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a testbed aircraft.

TRL 8—Actual System Completed and Flight Qualified Through Test and Demonstration. Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TR represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.

TRL 9—Actual System Flight Proven Through Successful Mission Operations. Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last bug fixing aspects of true system development. Examples include using the system under operational mission conditions.

STO/DTO MAPPING

The following table lists those Army Strategic Research Objectives that are also Defense Technology Objectives.

Technology Subarea	STOs	DTOs
	AVIATION	
RWV—Aeromechanics	IV.AV.1997.01 Advanced Rotorcraft Aeromechanics Technologies IV.AV.1999.01 Variable Geometry Advanced Rotor Technology IV.AV.2000.03 Low-Cost Active Rotor	AP.07 Demonstration of Advanced Rotor Concepts AP.23 Low-Cost Active Rotor
RWV—Flight Control	III.AV.1996.01 Helicopter Active Control Technology	AP.06 Helicopter Active Control Technology
RWV—Structures	III.AV.1997.01 Rotary-Wing Structures Technology	AP.14 Rotary-Wing Vehicles Structures Technology
RWV—Subsystems & Platform Technologies	IV.AV.2000.01 Rotorcraft Enhanced Survivability Technologies IV.AV.2000.02 Rotorcraft Open Systems Avionics	AP.24 Rotorcraft Enhanced Survival Technologies SE.84 Platform Independent Open Systems Architectures
RWV—Rotorcraft Drives	III.AV.2001.01 Rotorcraft Drive System/21st Century	AP.25 Rotorcraft Drive System 21st Century
Integrated High-Performance Turbine Engine Technology	III.AV.1998.04 Integrated High-Performance Turbine Engine Technology Joint Turbine	AP.09 Transport/Patrol/Helicopter Propulsion
Guidance and Control	III.AV.1999.02 Modernized Hellfire/Common Missile	WE.61 Modernized Hellfire Guidance and Control/Seeker Technology Effort
Precision Force (Joint)	III.AV.1999.03 Low-Cost, Precision-Kill 2.75-Inch Guided Rocket ATD	B.18 Low-Cost Precision Kill
	COMMAND, CONTROL, COMMUNICATIONS, AND COMPUTERS	
Decisionmaking	III.C4.1998.01 Theater Precision Strike Operations III.C4. 1999.03 Advanced Combat Identification Architecture III.C4.2000.01 Agile Commander ATD IV.C4.1998.01 Advanced Battlefield Processing Technology IV.C4.2000.01 Dynamic Readdressing & Management for Army 2010	B.25 Theater Precision Strike Operations ACTD C.08 Advanced Combat Identification Capability IS.47 Future Command Post Technologies IS.02 Forecasting, Planning, and Resource Allocation IS.03 Integrated Force & Execution Management IS.01 Consistent Battlespace Understanding
Information Assurance	III.C4.1997.02 Tactical Command & Control Protect ATD III.C4.1999.01 On-the-Move Tactical Satellite Communications Technology IV.C4.1999.02 Dismounted Warrior Command, Control, Communications, Computers, & Intelligence Technologies	A.12 Information Dominance (Command & Control Protect & Attack for I/O ATD) IS.23 Digital Warfighter Communications E.01 Small-Unit Operations
Seamless Communications	III.C4.1997.01 Army Communications Integration & Cosite Mitigation III.C4.2000.02 Multifunctional On-the-Move Secure Adaptive Communications III.C4.2001.02 Advanced Antennas IV.C4.1997.01 Antennas for Communications Across the Spectrum IV.C4.1997.02 Personal Communications System for the Soldier	IS.38 Antenna Technologies IS.49 Smart Networked Radio IS.20 Communications Infrastructure Mobility IS.65 Advanced Antennas IS.38 Antenna Technologies E.01 Small-Unit Operations
	INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE AND ELECTRONIC WARFARE	
Electronic Threat Warning	III.IS.1999.02 Joint Intelligence, Surveillance, & Reconnaissance	A.35 Joint Intelligence, Surveillance, & Reconnaissance ACTD
	ELECTRONIC WARFARE	
Electronic Threat Warning	IV.BA.1998.03 Three-Dimensional Dynamic Multispectral Synthetic Scene Visualization IV.EW.1998.02 Advanced Electronic Warfare Sensors	H.10 Precision EW Situation Awareness, Targeting, & SEAD Demonstrations SE.80 Advanced Electronic Warfare Sensors
Electronic Mission Support	IV.EW.1998.01 Low-Cost Electro-Optic/Infrared Countermeasures IV.EW.2000.01 Advanced Radar Deception & Countermeasures	SE.79 Low-Cost Electro-Optic/Infrared Countermeasures SE.78 Advanced Radar Deception & Countermeasures

Technology Subarea	STOs	DTOs
GROUND COMBAT & TACTICAL SYSTEMS		
Systems Integration	III.GC.1997.01 Future Scout & Cavalry System III.GC.2000.03 Future Combat Systems IV.GC.1998.01 Combat Vehicle Concepts & Analysis IV.GC.2000.01 Concepts for 21st Century Truck-Based Tactical Vehicles	GV.01 Future Scout & Cavalry System M.15 Future Combat Systems GV.20 Crew Integration & Automation Testbed
Integrated Survivability	III.GC.1999.01 Full Spectrum Active Protection IV.GC.2000.02 Ballistic Protection for Future Combat Systems	GV.13 Integrated Hit/Kill Avoidance Optimization
Mobility	III.GC.1996.01 Ground Propulsion & Mobility IV.GC.1999.01 Combat Hybrid Power Systems	GV.04 Advanced Ground Vehicle Mobility Systems GV.16 Combat Hybrid Power Systems
Vehicle Electronics	III.GC.1999.02 Crew Integration & Automation Testbed ATD	GV.03 Ground Vehicle Electronic Systems GV.20 Crew Integration & Automation Technology
Robotics	III.GC.2000.04 Robotic Follower ATD	GV.17 Unmanned Ground Mobility
WEAPONS		
Guidance & Control	IV.WP.1999.02 Point-Hit Multiple Launch Rocket System	B.27 Point-Hit ATACMS/Multiple Launch Rocket System
Guns—Conventional & Electric	III.WP.1996.02 Objective Crew-Served Weapon ATD III.WP.1999.01 Multirole Armament & Munition ATD III.WP.2000.02 Advanced Light Armaments for Combat	WE.34 Objective Crew-Served Weapon ATD WE.74 Multirole Electrothermal-Chemical Armament for Future Combat Systems WE.64 Advanced Light Armament for Combat Vehicles
Missiles	III.AV.1999.02 Modernized Hellfire/Common Missile III.AV.1999.03 Low-Cost Precision-Kill 2.75-Inch Guided Rocket III.WP.1999.03 Compact Kinetic-Energy Missile Technology	WE.61 Modernized Hellfire Guidance & Control/Seeker Technology Effort B.18 Low-Cost Precision Kill WE.50 Compact Kinetic-Energy Missile Technology
Ordnance	III.WP.1996.01 Direct-Fire Lethality ATD III.WP.1994.01 Precision-Guided Mortar Munition ATD IV.WP.2000.01 Loitering Attack Munition—Aviation	WE.18 Direct-Fire Lethality ATD M.06 Precision-Guided Mortar Munition ATD WE.75 Loitering Attack Munition—Aviation
SOLDIER SYSTEMS		
Warrior Protection & Sustainment	III.SH.1997.01 Military Operations in Urbanized Terrain	E.02 Military Operations in Urbanized Terrain ACTD
SOLDIER AND PERSONNEL TECHNOLOGIES		
Information Display & Performance Enhancement	IV.SP.1998.01 Cognitive Engineering of the Digital Battlefield	HS.06 Joint Cognitive Systems for Battlespace Dominance
Warrior Protection & Sustainment	III.LG.2000.02 Combat Rations for Enhanced Warfighter Logistics III.LG.2000.03 Precision Roll-On/Roll-Off Air Delivery IV.SP.1997.01 Multifunctional Fabric System IV.SP.1998.02 Ballistic Protection for Improved Individual Survivability IV.SP.1999.02 Load Carriage Optimization for Enhanced Warfighter Performance	HS.31 Combat Rations for Enhanced Warfighter Logistics HS.18 Precision-Offset, High-Glide Aerial Delivery of Munitions and Equipment HS.25 Multifunctional Fabric System HS.05 Ballistic Protection for Individual Survivability M.12 Load Carriage Optimization for Enhanced Warfighter Performance
Personnel Performance & Training	III.PE.1996.01 Training Strategies for the Objective Force IV.SP.1997.03 Computer-Generated Forces IV.SP.1998.01 Cognitive Engineering of the Digital Battlefield IV.SP.1999.03 Simulation-Based Aviator Training IV.SP.1999.04 New Assessment Techniques To Maximize 21st Century Noncommissioned Officer Performance IV.SP.1999.05 Virtual Environments for Dismounted Soldier Simulation, Training, & Mission Rehearsal IV.SP.1999.06 Advanced Tactical Engagement Simulations IV.SP.2001.02 Advanced Trauma Patient Simulation	HS.11 Force XXI Training Strategies IS.61 Human Behavior Representation HS.06 Joint Cognitive Systems for Battlespace Dominance HS.28 Distributed Mission Warfighting Training Techniques & Technologies HS.29 Maximizing 21st Century Noncommissioned Officer Performance IS.40 Individual Combatant and Small-Unit Operations Simulation F.32 Advanced Trauma Patient Simulation

Technology Subarea	STOs	DTOs
	BIOMEDICAL	
Infectious Diseases of Military Importance	III.ME.1996.02 Drug to Treat Multidrug Resistant & Severe & Complicated Malaria III.ME.1998.02 Common Diagnostic Systems for Biological Threats & Endemic Infectious Diseases III.ME.2000.01 A Multiantigen, Multistage *Plasmodium vivax* Malaria Vaccine IV.ME.1996.01 A Multistage, Multiantigen *Plasmodium falciparum* Malaria Vaccine IV.ME.1999.03 Prevention of Diarrheal Diseases	MD.12 Drugs for Prevention and Treatment of Malaria CB.26 Common Diagnostic Systems for Biological Threats & Endemic Infectious Diseases MD.02 Vaccines for Prevention of Malaria MD.06 Prevention of Diarrheal Diseases MD.02 Vaccines for Prevention of Malaria
Medical Chemical & Biological Defense	III.ME.1998.02 Common Diagnostic Systems for Biological Threats & Endemic Infectious Diseases TD III.ME.1998.01 Multiagent Vaccines for Biological Threat Agents	CB.26 Common Diagnostic Systems for Biological Threats & Endemic Infectious Diseases CB.25 Multiagent Vaccines for Biological Threat Agents
Military Operational Medicine	IV.ME.1997.02 Optimization of Physical Performance IV.ME.1997.03 Laser Bioeffects & Treatment IV.ME.2000.05 Innovative Strategies to Assess Health Risk from Environmental Exposure to Toxic Chemicals IV.ME.2000.06 Inhalation Injury and Toxicology Models	MD.19 Optimization of Physical Health & Readiness MD.08 Laser Bioeffects Countermeasures MD.10 Deployment Toxic Hazard Assessment Tools
Combat Casualty Care	III.ME.1999.02 Joint Medical Operations—Telemedicine ACTD III.ME.2001.02 Field Medical Monitoring and Therapeutic Devices for Casualty Care IV.ME.2001.02 Optimal Parameters for Battlefield Resuscitation of Combat Casualties IV.ME.2001.03 Hemorrhage Control	F.27 Joint Medical Operations—Telemedicine ACTD MD.26 Field Medical Monitoring and Therapeutic Devices for Casualty Care MD.28 Far-Forward Treatment of Trauma MD.27 Hemorrhage Control
	ENGINEERING, COMBAT CONSTRUCTION, MOBILITY, AND COUNTERMOBILITY	
Topographic Engineering	III.EN.1996.01 Rapid Terrain Visualization ACTD	A.06 Rapid Terrain Visualization ACTD
Mobility	III.EN.1997.01 Advanced Mine Detection Sensors III.EN.1999.01 Lightweight Airborne Multispectral Minefield Detection III.LG.1998.02 Enhanced Coastal Trafficability & Sea State Mitigation	G.11 Advanced Minefield Detection Sensors G.12 Lightweight Airborne Multispectral Minefield Detection MP.28.01 Enhanced Coastal Trafficability & Sea state Mitigation for Logistics-Over-the-Shore ATD
Civil Engineering and Environmental Quality	IV.EN.1997.01 Sustainable Military Use & Stewardship of Army Lands IV.EN.1997.02 Munitions Production Compliance Technology IV.EN.1999.01 Environmental Cleanup IV.EN.1998.01 Airfields & Pavements to Support Force Protection IV.EN.1998.04 Force Protection Against Terrorist Threats IV.EN.1999.02 Buried Unexploded Ordnance	MP.30.01 Sustainable Military Use & Stewardship of the Environment MP.17.06 Hazardous & Toxic Waste Treatment/Destruction for DoD Operations MP.18.06 Cleanup of Contaminants MP.17.11 Airfields & Pavements to Support Force Projection L.06 Mitigation of Terrorist Attacks on Key Facilities MP.41 Enhanced Detection, Discrimination, & Characterization of Buried Unexploded Ordnance for Environmental Remediation & Active Range Clearance
	LOGISTICS	
Early Entry & Resupply	III.LG.1998.01 Reforming Diesel (Cogeneration) III.LG.1999.02 Wide-Span Airbeam Shelter for Logistics Applications III.LG.2000.02 Combat Rations for Enhanced Warfighter Logistics	HS.22 Cogeneration for Field Services MP.14.11 Wartime Contingencies & Bare Airbase Operations HS.31 Combat Rations for Enhanced Warfighter Logistics
Logistics Demand Reduction—Resupply	III.LG.1998.02 Enhanced Coastal Trafficability & Sea State Mitigation	MP.28.01 Enhanced Coastal Trafficability & Sea State Mitigation for Logistics-Over-the-Shore
Logistics Command & Control—Situational Understanding	III.LG.1999.01 Logistics Command & Control	IS.02 Forecasting, Planning, & Resource Allocation
Logistics Demand Reduction—Power & Energy	IV.LG.1997.01 High-Energy, Cost-Effective Primary & Rechargeable Batteries	SE.43 Energy Conversion/Power Generation

Technology Subarea	STOs	DTOs
MATERIALS, MATERIAL PROCESSES, AND STRUCTURES		
Materials	IV.MA.2001.01 Metal Matrix Composites for Ordnance Applications	MP.45 Metal Matrix Composites for Ordnance Applications
SENSORS AND ELECTRONICS		
Sensors	III.IS.1996.01 Multimission/Common Modular Unmanned Aerial Vehicle Sensors ATD III.GC.1997.02 Multifunction Staring Sensor Suite ATD III.SH.1999.01 Low-Power Uncooled Infrared Sensor IV.SN.2000.01 Advanced Acoustic/Seismic System IV.SN.1996.01 Advanced Focal Plane Array Technology IV.SN.1997.01 Near-Infrared Sensors IV.SN.1997.03 Integrated Sensor Modeling and Simulation IV.SN.1998.02 Low-Cost, Electronically Scanned Antennas IV.SN.1999.01 Third-Generation Infrared Imaging Technology IV.SN.1999.02 Warrior Extended Battlespace Sensors	A.11 Counter-Camouflage Concealment and Deception ATD B.26 Multifunction Staring Sensor Suite ATD SE.85 Target Detection, Location, & Noncooperative Identification SE.69 Autonomous Distributed Sensors SE.33 Advanced Focal Plane Array Technology SE.59 Low-Light-Level Imaging Sensors SE.19 Affordable ATR via Rapid Design, Evaluation, and Simulation SE.71 Advanced Multifunction Radio Frequency Systems Components SE.65 Long-Wavelength & Multispectral, Large-Area, Staring Focal Plane Arrays SE.70 Integrated Compact Electronic Sensors & Components
Electronics	IV.LG.1997.01 High-Energy, Cost-Effective Primary & Rechargeable Batteries IV.SN.2000.04 Spectral/Spatial Data Exploitation for Terrain Categorization & Target Identification	SE.43 Energy Conversion/Power Generation SE.67 Hyperspectral Applications Technology
BATTLESPACE ENVIRONMENT		
Terrestrial Environment	IV.BA.1998.02 Rapid Mapping Technology TD	SE.68 Rapid Mapping Technology
Lower Atmosphere Environment	IV.BA.1999.01 Profiler Data Fusion TD IV.BA.2000.01 Deep Attack & Indirect Fire Meteorological Improvement TD IV.BA.1997.02 Weather Effects & Battlescale Forecasts for Combat Simulation & Training TD IV.BA.1997.01 Weather Impacts & Decision Aids for Mission Rehearsal, Training, & Battle TD	SE.53 On-Scene Weather Sensing & Prediction Capability SE.52 Weather/Atmospheric Impacts on Sensor Systems

ANNEX

B ADVANCED TECHNOLOGY DEMONSTRATIONS

CONTENTS

ANNEX

B ADVANCED TECHNOLOGY DEMONSTRATIONS

The Advanced Technology Demonstrations (ATDs) seek to demonstrate the potential for enhanced military operational capability or cost effectiveness. Active participation by a Training and Doctrine Command (TRADOC) school, as well as the materiel developer, is required throughout the demonstration. At least one demonstration at a TRADOC battle laboratory, as well as an advanced simulation, is required. This helps the TRADOC schools develop more informed requirements and the materiel developer reduce risk prior to the initiation of full-scale system development.

ATDs are characterized by:

- Relatively large scale in resources and complexity but typically focused on an individual system or subsystem.
- Operator/user involvement from planning to final documentation.
- Testing with soldiers in a real or synthetic operational environment.
- Exit criteria approved by both the materiel developer and TRADOC.
- The requirement to be fully funded, typically with 6.3 advanced technology development funds.
- Finite schedule, typically 5 years or less.

Eighteen Army ATDs are briefly described on the following pages.

Precision-Guided Mortar Munition ATD

(STO III.WP.1994.01)

<u>Concept Description:</u>

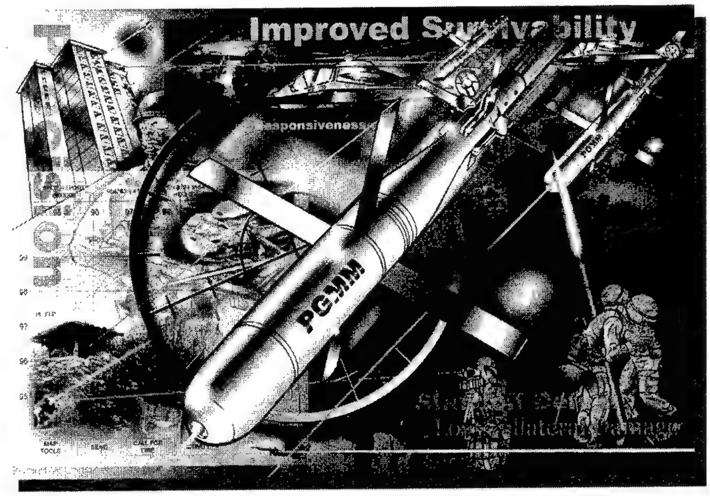
- 120-mm laser guided mortar with extended range capability.

<u>Core Benefit:</u>

- Responsive, standoff precision lethality for highly deployable and mobile forces.

<u>Affordability Approach:</u>

- Cost drivers for previous laser guided systems identified as the gimbaled laser seeker and gimbaled gyro.
- ATD seeks to control unit costs by using strapdown gyros and seekers.
    - Increasing processor speeds, along with MEMS-based sensor technology is now emerging to make strapdown guidance affordable.
- Control O&S costs by using existing 120-mm mortar infrastructure – no new force structure requirements.



What is the problem?

Maneuver commander does not have a capability to responsively defeat high-value point targets from a distance while minimizing collateral damage.

What are the barriers to solving this problem?

Precision munition accuracy at an affordable cost (gimbaled gyros and gimbaled seekers are expensive).

What is the product of this STO?

Hi-G survivable technology demonstrator 120-mm mortar round that integrates strapdown guidance with maneuverable airframe capable of extended range flight.

What are the quantitative metrics?

Criteria	Today	Threshold	Goal
Terminal Accuracy	60m CEP (w/MFCS)	2m CEP	1m CEP
Range	7.2km	12km	15km
Length	30"	40"	30"
Weight	30lb	40lb	30lb

What is the warfighter payoff?

Responsive, standoff precision lethality for highly deployable and mobile forces.

Can be employed when collateral damage is an issue.

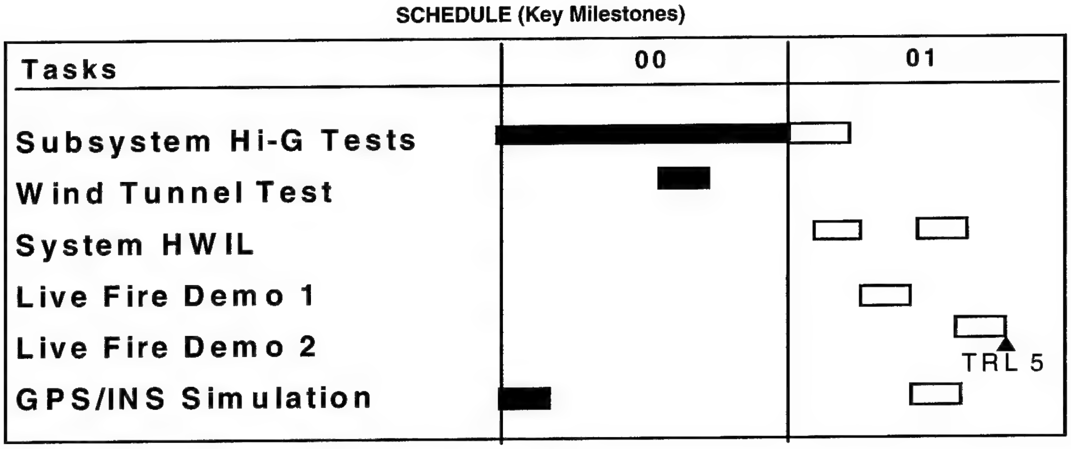
Enables mortar to engage a full spectrum of targets.

Improved survivability and OPTEMPO.

What are the transition milestones?

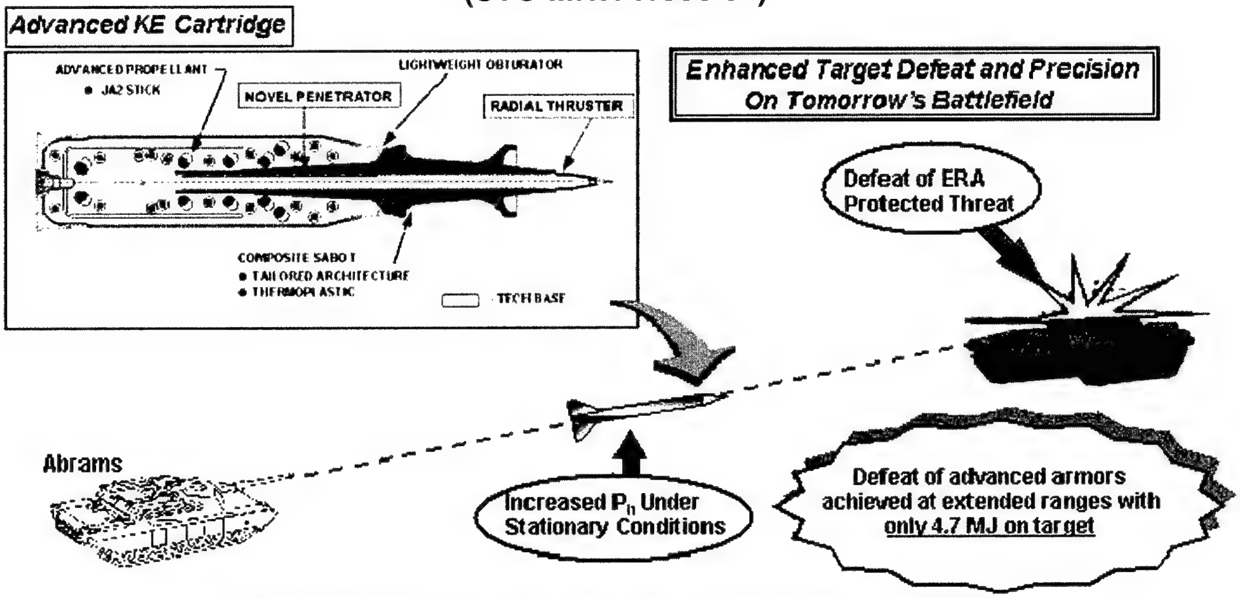
Transitions to PGMM System Development and Demonstration in FY02.

SCHEDULE (Key Milestones)



Direct-Fire Lethality ATD

(STO III.WP.1996.01)



- Demonstrate defeat of ERA protected threats and increased system accuracy
- Demonstrate 40–70% RHAe penetration increase over M829A2 at extended ranges
- 30–70% increase in P_h at 3 km under stationary conditions
- UPC < $4,200

What is the problem?

Advancements in future threat armor will diminish performance of kinetic energy (KE) ammunition threatening Abrams lethality overmatch capability.

System accuracy reduced at extended range.

What are the barriers to solving this problem?

Explosive reactive armor degrades the coventional penetrator's capability to penetrate base armor.

Launch induced lateral accelerations are the primary cause of errors in projectile trajectory.

What is the product of this STO?

System (lethality) and subsystem (accuracy) demonstration of a 120-mm advanced KE cartridge.

Penetrator technology for engineering and manufacturing development.

Radial thruster for program definition and risk reduction.

What are the quantitative metrics?

Current lethality: M829A2 @ 3 km
Minimal acceptable: A2 + 40%
Goal: A2 + 70%

Current accuracy (P_h): M829A2 @ 3 km
Minimal acceptable: A2 + 30%
Goal: A2 + 70%

What is the warfighter payoff?

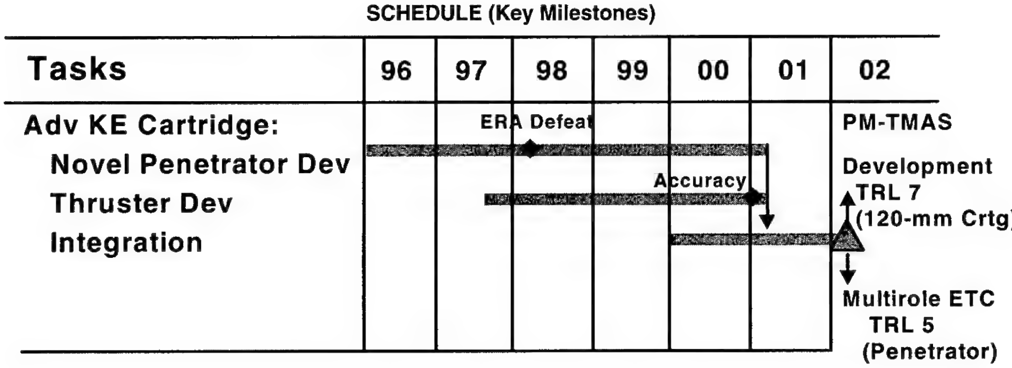
Maintain Abrams lethality overmatch against future threats at extended ranges and incrased P^h

What are the transition milestones?

Transition (end FY01) to Program Manager—Tank and Medium-Caliber Armament Systems (PM–TMAS) follow-on developments.

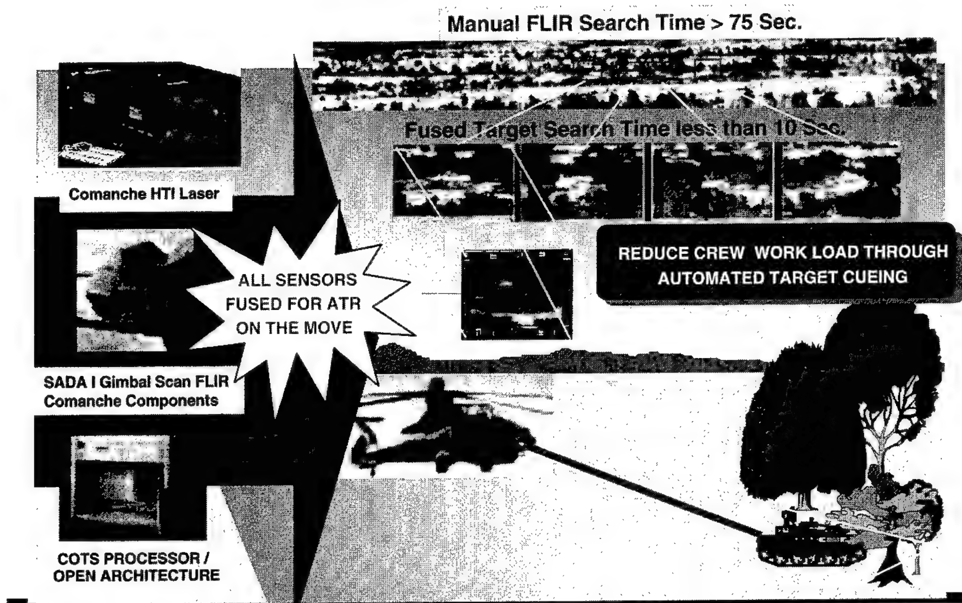
Transition to Multirole Armaments and Ammunition ATD in FY02.

SCHEDULE (Key Milestones)



Air/Land Enhanced Reconnaissance and Targeting ATD

(STO III.AV.1996.02)



Automated On-The-Move Wide Area Search for Effective Targeting and Survivable Ingress and Egress

What is the problem?

Current electro-optical (EO) aviation target acquisition systems employ manual area search and target reporting, which are time and crew intensive, limiting the platform's lethality and survivability.

What are the barriers to solving this problem?

Lack capability to resolve low signal-to-noise ratio targets at extended ranges.

Lack algorithms for image artifact registration and correlation for moving target indication (MTI) and search on-the-move (SOM).

What is the product of this STO?

Aided target detection and classification (ATD/C) algorithms.

Model second-generation Standard Advanced Dewar Assembly forward looking infrared (FLIR) range performance.

Ranging capability of the Comanche multifunction laser.

What are the quantitative metrics?

Current capability: FLIR only, limited range, no search SOM/ EO MT.

Minimum: 0.8X static Comanche operational requirements document (ORD) on-the-move (OTM).

Goal: OTM ATD/C at Comanche ORD parameters.

What is the warfighter payoff?

Reduced target acquisition timeline/increased survivability.

Increased target acquisition range/lethality.

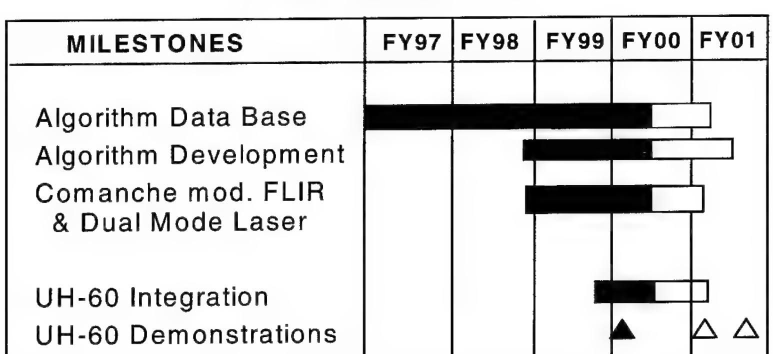
Reduced crew work load.

Evaluation of long-wave IR gimbal scan aided target recognition for Future Combat Systems

What are the transition milestones?

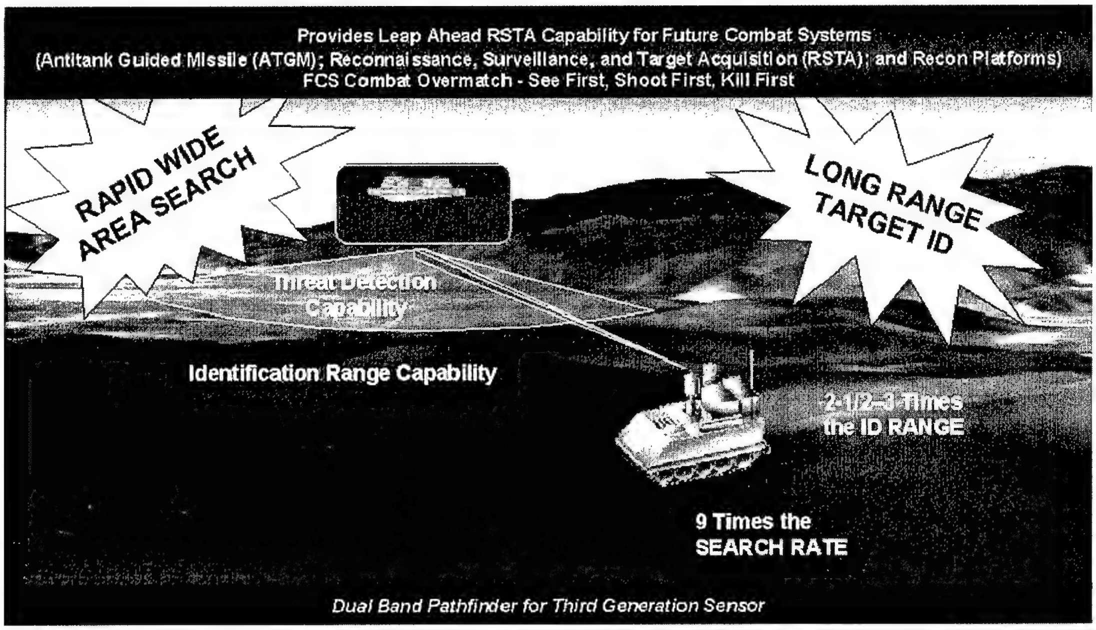
ATD/C algorithms to PM–Comanche 4QFY01.

SCHEDULE (Key Milestones)



Multifunction Staring Sensor Suite ATD

(STO III.GC.1997.02)



What is the problem?

Present ground platform sensor cannot identify threat targets before being detected, detect and identify targets in cluttered backgrounds, and rapidly search wide field of regard.

What are the barriers to solving this problem?

Inadequate resolution at tactical apertures.

High thermal clutter resulting in excessive false alarms for aided search approaches.

What is the product of this STO?

Prototype MFS^3 with multispectral aided target detection and mid-wave aided target detection/aided target recognition (ATR) for on-the-move evaluation in field demonstrations with simulated operational conditions.

Prototype system to Future Combat Systems (FCS) system-of-systems demonstration (FY03).

What are the quantitative metrics?

Baseline: ID manual (90%) 1.0X, field of regard 180×9, time to detect 90 seconds.

Minimum: ID manual (905) 2.8X, ATRD/R (50 OTM) $2.8 \times (2.2)$, field of regard 180×9, time to detect 10 seconds.

Goal: ID manual (90%) 3.5X, ATRD/R (50% OTM) $3.5 \times (2.8)$, field of regard 360×8, time to detect 10 seconds.

What is the warfighter payoff?

Minimizes friendly fire losses in coalition environments.

Identify threat targets before detection by the enemy.

Find and recognize camouflaged threats in defilade.

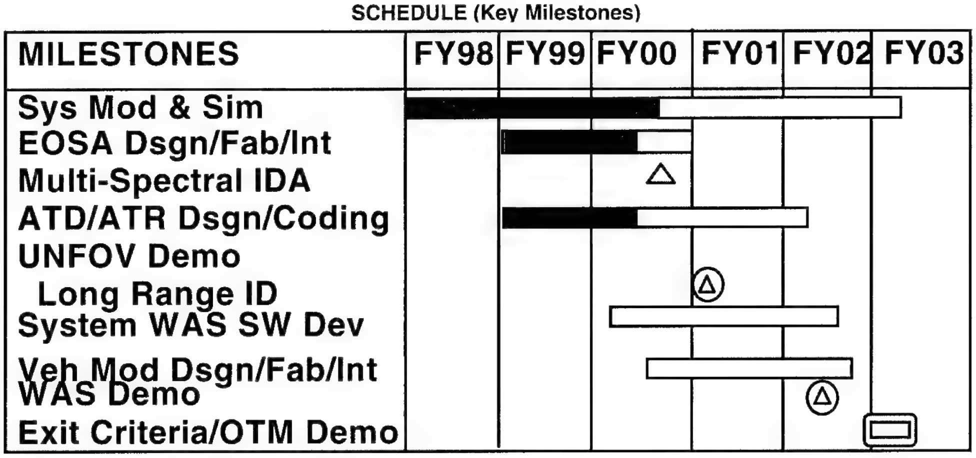
Acquire threat targets quickly without radiating.

Increase vehicle and soldier survivability.

What are the transition milestones?

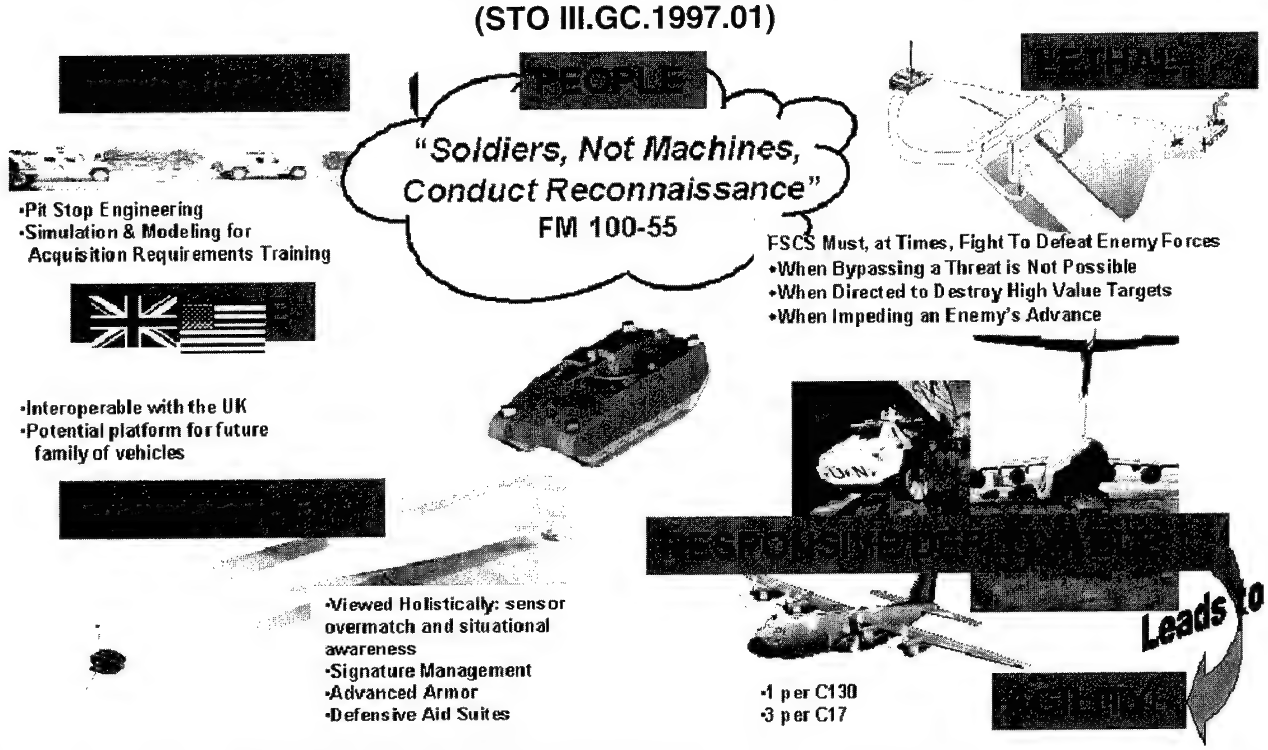
FCS system-of-systems demonstration in FY03.

SCHEDULE (Key Milestones)



Future Scout and Cavalry System ATD

(STO III.GC.1997.01)



What is the problem?

Current ground scout vehicles are either too heavy/large for rapid deployability or too vulnerable to small arms fire.

What are the barriers to solving this problem?

Maintaining required armor protection levels while minimizing vehicle weight and size for C–130 transportability.

Integration of multispectral signature treatements.

Integrated target acquisition and sensor suite using data and sensor fusion.

What is the product of this STO?

Integrated platform to demonstrate operational potential of a lightweight scout vehicle.

Tradeoff analysis, system definition, interface definition, design, requirements and specification refinement and validation, risk mitigation, and planning and costing required for an optimized FSCS.

What are the quantitative metrics?

Current achievable signature: baseline
Minimum acceptable signature: 30% less
Goal signature: 50% less

Current achievable target detection: 90 seconds
Minimum acceptable target detection: 20 seconds
Goal target detection: 10 seconds

Current achievable target ID range: 2nd-generation FLIR
Minimum acceptable target ID range: 50% more
Goal target ID range: 250% more

What is the warfighter payoff?

Information-based warfare.

Survivability through mobility, countermeasures, and stealth.

Precision target engagement.

Reduced fuel and logistics.

Rapid deployability.

Reduced training aids, devices simulators, and simulations.

Advanced human factors integration.

What are the transition milestones?

Enabling technologies for FCS in FY02.

Preplanned product improvement for Interim Armored Vehicle (IAV).

SCHEDULE (Key Milestones)

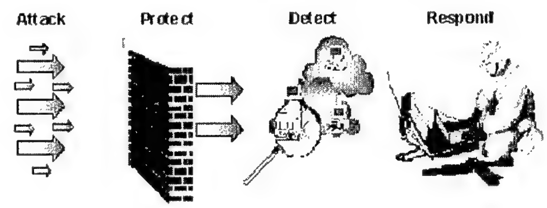
Tasks	FY98	FY99	FY00	FY01	FY02
Design/Build Crew Station Simulators					
Award ATD Contracts		▲			
Tradeoffs/Design FSCS ATD					
Fabricate FSCS ATD					
3-Star Affordability Review				▲	
Develop FSCS Virt Prototype					
Demo/Test HW/SW In SIL					
Demonstrate/Test FSCS ATD					
Govt AoA and CAIV analysis					

Tactical Command and Control Protect ATD

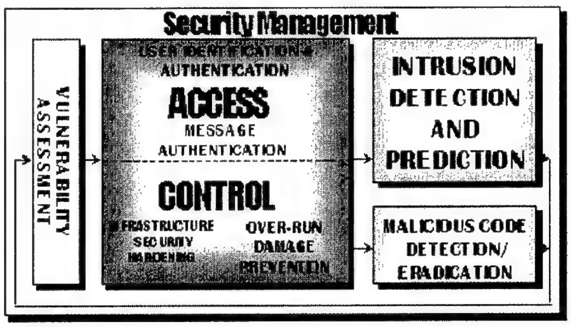
(STO III.C4.1997.02)

Technical Objective: Develop, integrate, validate, and demonstrate hardware and software that protects the systems and networks of the First Digitized Division (FDD) and Objective Force/Future Combat Systems.

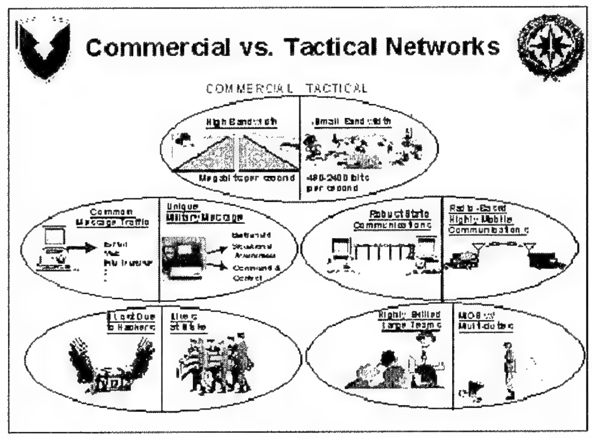
C2 Protect Elements



C2 Protect Areas of Investigation



Affordability measures include leveraging, modeling and simulation, software solutions, and automated processes.



What is the problem?

The Army's tactical information networks and Objective Force/Future Combat Systems (FCS) are inadequately protected against modern network attacks.

What are the barriers to solving this problem?

Lack of robust network access control and intrusion detection measures, malicious code detection, and security management.

Most off-the-shelf products not suited for tactical environment due to bandwidth constraints, message types, and mobile networking.

What is the product of this STO?

Software tools that will protect, detect, and respond to network intrusions that have been validated via Red Teaming, in addition to an integrated security management system.

What are the quantitative metrics?

Currently capability: no network intrusion detection, weak passwords, inability to detect unauthorized access.

Minimum capability: detection of attack 75%, passwords resistant to attack 95%, prevention of unauthorized access 80%, integrated security tools with minimal overhead 10%.

Goal: detection of attack 90%, prevent unauthorized access 99%, and reduce security tools overhead to 5%.

What is the warfighter payoff?

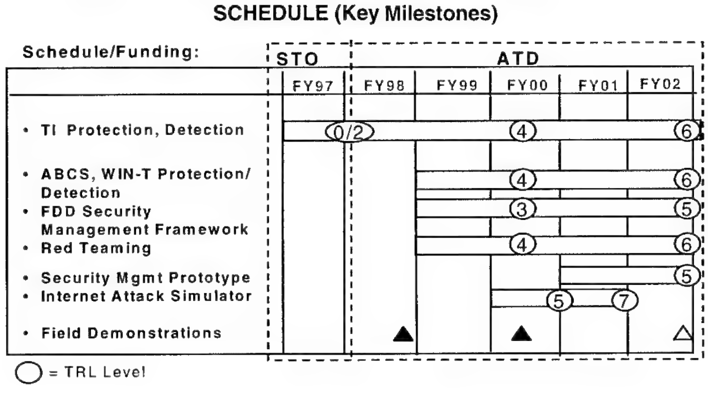
Prevention and detection of unauthorized penetration and monitoring, computer virus detection, and robust user authentication. Increased user confidence resulting from improved network and security posture. Limit compromise in overrun situations.

What are the transition milestones?

Transition technologies to respective platforms as they become available (i.e., FY00: PMs Force XXI Battle Command Brigade and Below and Platforms; FY01: PMs Warfighter Information Network—Terrestrial and Platforms).

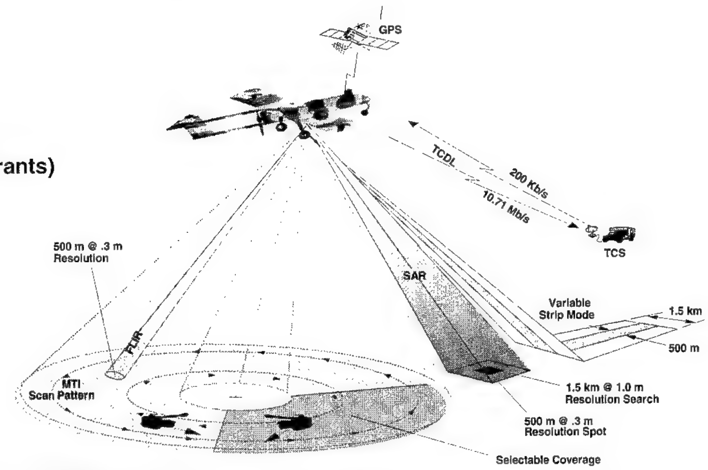
Demonstrate C^2 Protect technologies during field tests in FY00 and FY02.

SCHEDULE (Key Milestones)



Multimission/Common Modular Unmanned Aerial Vehicle Sensors ATD

(STO III.IS.1996.01)



- Day/night, adverse weather/atmospheric conditions capability (4 mm rain, fog, clouds, battlefield obscurants)
- Enhances RSTA of moving and stationary targets
- Enhances TUAV and medium brigade survivability
- Improves battle damage assessment
- Targeting of NLOS weapons
- Information superiority
- Affordable
  > Production costs defined in exit criteria and is part of EO/IR and radar contracts
  > EO/IR: TV and IR cameras, gimbal based on standard models
  > Common radar modules: parts control, producibility, logistics, configuration management
    •• Decreased design 7 pounds

What is the problem?

Detection and location of targets in adverse weather and through battlefield obscurants.

Sensor-to-shooter timeline needs to be shortened.

What are the barriers to solving this problem?

Current radars are too heavy and costly for tactical unmanned aerial vehicle (TUAV).

Require large optics for sensors with sufficient resolution and sensitivity.

What is the product of this STO?

Modular/common architecture for electro-optical (EO)/infrared (IR) and synthetic aperture radar (SAR)/moving target indicator (MTI) payloads for tactical class UAVs.

Lightweight, high-resolution SAR/MTI radar.

Improved EO/IR.

What are the quantitative metrics?

Range: EO/IR 4–10 km, SAR 3–10 km, MTI 3–14 km.

Target location accuracy: EO/IR 80 m, SAR 50 m, MTI 100 m.

Weight: EO/IR 50 lbs, SAR/MTI 63 lbs.

What is the warfighter payoff?

Enhanced reconnaissance, surveillance, battle damage assessment, and targeting for non-line-of-sight weapons.

Real-time target acquisition, identification, and dissemination.

Affordable, lightweight, module, sensor suite for TUAVs.

What are the transition milestones?

Transition to PEO/IEW&S (EMD/LRIP): EO/IR 1QFY03, SAR/MTI 1QFY02.

SCHEDULE (Key Milestones)

Tasks	FY 97	FY98	FY99	FY00	FY01
SAR/MTI Design					
SAR/MTI Integration & Flight Test					
EO/IR Design					
EO/IR Integration & Flight Test (2 units)					
User Demos/AWEs					

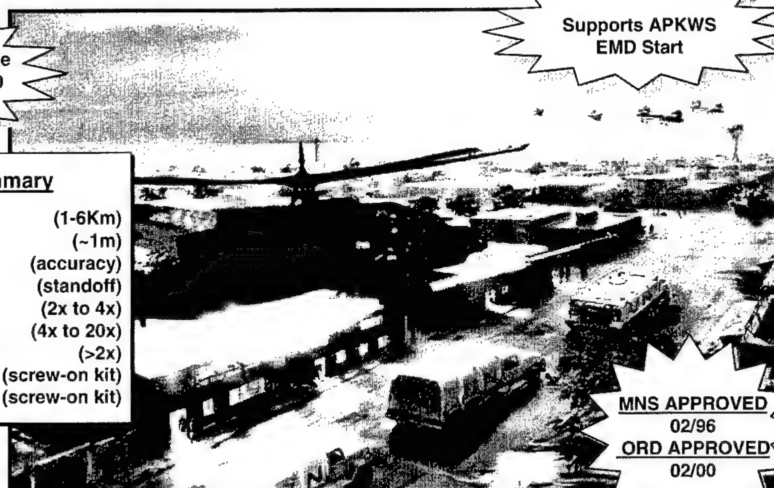
Low-Cost Precision Kill 2.75-Inch Guided Rocket ATD

(STO III.AV.1999.03)

Project Objective: Develop, flight demonstrate, and integrate onto the AH-64 APACHE a low cost, accurate 2.75 inch guided rocket that provides a standoff range surgical strike capability against specified soft point targets

Provides precision strike capability to HYDRA-70 rockets

Supports APKWS EMD Start



Requirements Summary

- Hydra-70 range (1-6Km)
- HELLFIRE-like accuracy (~1m)
- Reduced fratricide (accuracy)
- Enhanced survivability (standoff)
- Reduced cost/kill (2x to 4x)
- Increased stowed kills (4x to 20x)
- Reduced collateral damage (>2x)
- Minimize platform mods (screw-on kit)
- Current logistics (screw-on kit)

MNS APPROVED 02/96
ORD APPROVED 02/00

What is the problem?

Small, low-cost, precision-guided weapon needed by Army Aviation to fill the gap between the Hydra–70 rocket and Hellfire for soft point targets.

What are the barriers to solving this problem?

Unproven low-cost mechanisms for precision guidance.

Control of high roll rate free rocket.

Lack of aerodynamic database for Hydra–70 rocket.

What is the product of this STO?

Flight demonstration of a precision-guided Hydra–70 rocket.

Integration kit developed for the AH–64D helicopter.

Mature industry products ready for transition into engineering and manufacturing development (EMD).

What are the quantitative metrics?

Current achievable capability: Hellfire >$50,000/rd, <1 m CEP, >6 km, ~100 pounds, over match for soft point targets.

Current achievable capability: Hydra–70 <$1,000/rd, >60 m CEP, >6 km, ~25 pounds, unacceptable accuracy for point targets

Minimum acceptable capability: <$10,000/rd, >1–2 m CEP, >5 km range, <35 pounds,

What is the warfighter payoff?

400% increase in stowed kills at a quarter the cost for non-tank targets.

Greater mission flexibility with reduced collateral damage.

Reduced logistics burden.

What are the transition milestones?

ATD transition in FY03 to a funded Advanced Precision Kill Weapon System SDD.

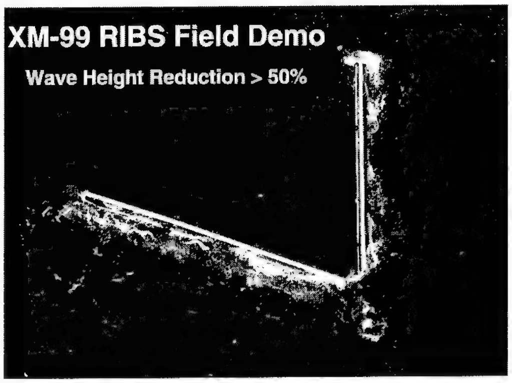
PEO–TM/AGMS PO has acquisition milestone authority.

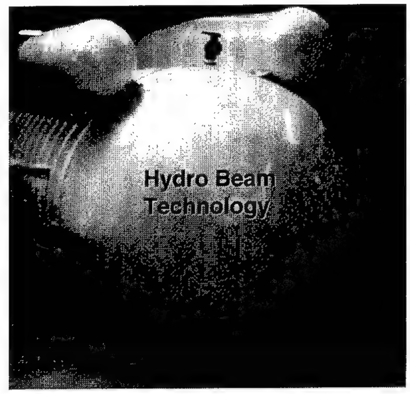
SCHEDULE (Key Milestones)

MILESTONE	FY99	FY00	FY01	FY02	FY03
ATD RFP	SSEB				
WIND TUNNEL, BALLISTIC FLTS					
CTV FLIGHTS					
GUIDED ROCKET DESIGN, FAB			GROUND	AIRBORNE	
GROUND BASED GUIDED FLTS		AOC			
GUIDED ROCKET PERF SPECS					
AIRCRAFT INTEGRATION					
AIRCRAFT GUIDED FLTS					
USER TESTS					
AIRCRAFT INTERFACE PERF SPECS					SDD RFP

Enhanced Coastal Trafficability and Sea State Mitigation ATD

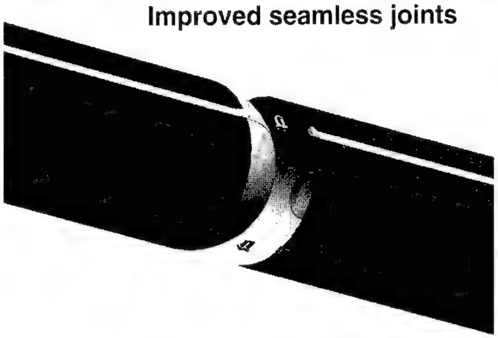
(STO III.LG.1998.02)





Improved seamless joints

Artist's rendition of ATD RIBS



Sections can be manufactured to any length

What is the problem?

Inability to conduct Joint Logistics Over-the-Shore (JLOTS) operations in high-wave conditions (0.9 to 1.52 m) is a "war stopper."

What are the barriers to solving this problem?

Development of mooring systems that do not interfere with operations.

Design of structure with sufficient stiffness to meet performance specifications while maintaining resilience for survivability.

What is the product of this STO?

Hardware system design for JLOTS.

What are the quantitative metrics?

Current capability: ship discharge limited to mid Sea State 2 (SS2) (<0.9 m).

Minimum acceptable capability: ship discharge through SS3 (0.9 to 1.52 m).

Goal: ship discharge through lower SS4.

What is the warfighter payoff?

Contributes significantly to meeting General Shinseki's mandate for 120-hour and 30-day force projection capability

Up to 100% increase in LOTS throughput for many areas of the globe.

30% increase in potential LOTS sites—requires enemy to plan/commit additional assets accordindly

What are the transition milestones?

Transition in FY02–03 to Program Manager—Force Projection Enabling Systems (PM–FPES).

SCHEDULE (Key Milestones)

Tasks	99	00	01	02
• Establish Structural Requirements				
• Complete Engineering Design for RIBS				
• Compete Design of Cross-Beach System				
• Fabricate Test RIBS				
• Demonstrate RIBS/Cross-Beach Capabilities				

Objective Crew-Served Weapon ATD

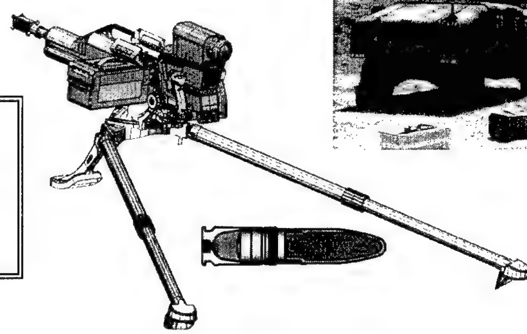
(STO III.WP.1996.02)

Provides the dismounted warfighter with a lightweight weapon system having <u>overwhelming lethality</u> at extended range and the capability to defeat protected, defilade targets & light armor

- 60+% lighter weapon system than M2 Cal 0.50 and MK19 40-mm GMG
- 50% reduction in cartridge weight
- Efficient and vverwhelming lethality to 2000 M
- 25-mm air-bursting munitions
- Defeats protected, defilade personnel, and lightly armored vehicles
- Lightweight, full solution fire control
- Secondary armament candidate for Future Combat Systems (FCS)

Affordability:

- Replaces 2–3 weapon systems
- Leveraging OICW MTO: warhead and fuzing
- Leveraging OICW MEMS S&A
- Leveraging Land Warrior electro-optics
- 3–12 times more kills per combat load



What is the problem?

Current crew-served weapon systems are too heavy and do not effectively defeat targets (personnel, light vehicles, defilade targets) at extended range.

What are the barriers to solving this problem?

Managing weapon recoil and miniaturizing fuzing.

Accurate 25-mm, high-explosive airburst munitions.

Lightweight, precision fire control solution.

What is the product of this STO?

A lightweight, crew-served weapon system, including the weapon, ground mount, traverse and elevation mechanism, fire control, and ammunition.

Independent safety, technical and user tests.

What are the quantitative metrics?

Armor-piercing warhead penetration of 2 inches rolled homogeneous armor (minimum), 2-inch high hardness armor (goal).

<50-pound weapon (i.e., total system)

Incapacitation probability 3X > MK19 (minimum), 6X (goal)

What is the warfighter payoff?

Overmatching lethality with defilade target defeat capability.

Lightweight, 2-man-portable, crew-served weapon system with lightweight, 25-mm airbursting munitions.

Increased survivability and standoff.

Improved target acquisition and situational awareness.

What are the transition milestones?

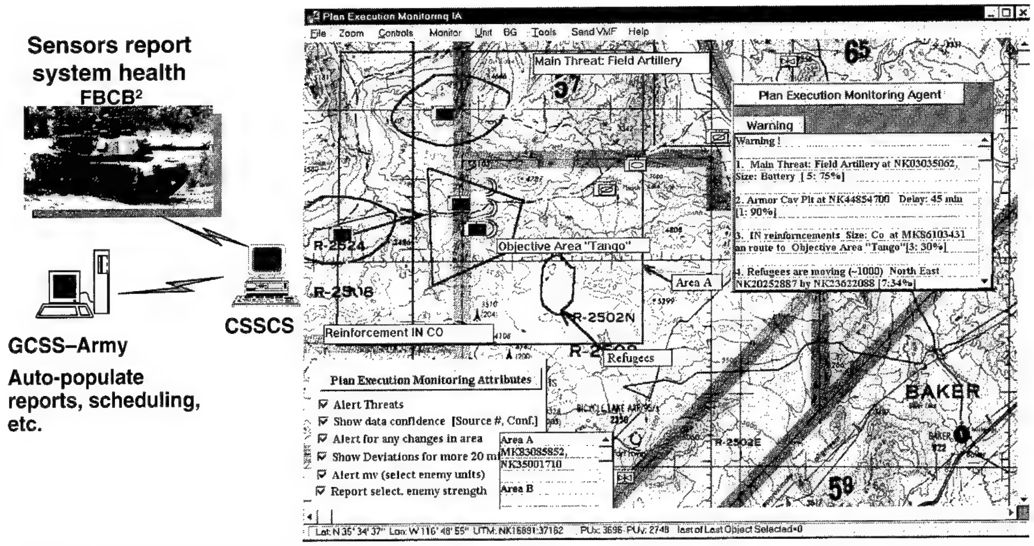
STO/ATD transitions to PM Small Arms for System Development and Demonstration start in FY03.

SCHEDULE (Key Milestones)

Tasks	FY99	FY00	FY01	FY02
• Demo Lightweight Weapon, Armor Piercing Warhead				
• Demo Rapid-Fire, Fuze-Set, Airburst				
• Demo Fire Control, FC Set Airburst				
• Demo Land Warrior / Thermal Module Interoperability				
• Safety / Technical Feasibility Tests				
• User Experiments				
• Transition to PMSA, Milestone B				

Logistics Command and Control ATD

(STO III.LG.1999.01)



- Collaboration, visualization & COA software
- Knowledge-base software development
- Data access, interoperability, and mediation
- Software intelligent agents for execution monitoring
- Affordability:
  100% segmented functionality
  100% DII COE of transitioned products
  100% security, communications, & training evaluated
  Sustainable – 100% open API code, 3 tier architecture

What is the problem?

Warfighters lack collaborative tools for logistics planning.

Logistics currently not readily integrted into maneuver plan.

What are the barriers to solving this problem?

Disparate databases.

Lack of collaborative planning automation.

Data overload.

What is the product of this STO?

Log C^2 simultion/stimulation prototype environment.

Map-based visualization and animation C^2 software for logistics.

Collaborative course of action (COA) generation and comparison software.

Intelligence agent software for alerts and optimization.

What are the quantitative metrics?

Current: 4–8 hours for three hasty COAs, 24-hour updates.

Minimum: 1–3 hours for five deliberate COAs, 1-hour updates, four map-based decision tools.

What is the warfighter payoff?

Faster OPTEMPO and a reduced footprint.

Bind the Combat Service Support (CSS) and OPLAN together.

Shorten CSS planning to within Force XXI 1-hour cycle.

What are the transition milestones?

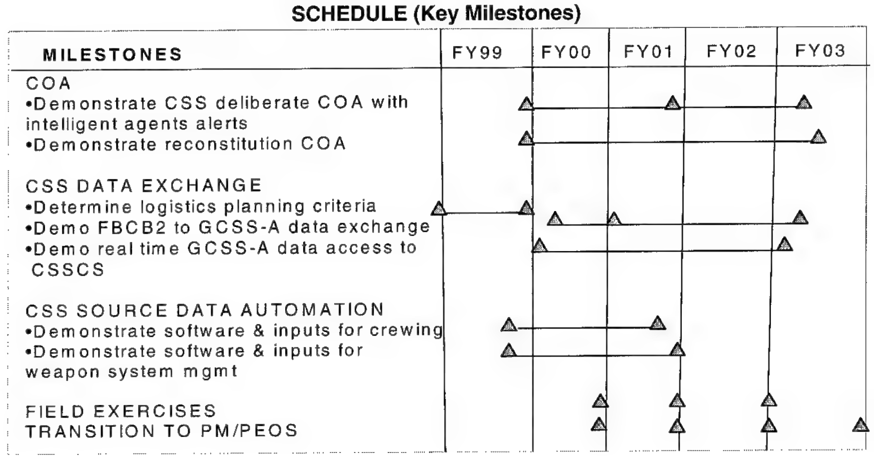
Data mediation software to CSS Control System (CSSCS) FY00.

Automatic alerts software to CSSCS FY01.

COA and decision support software tools to CSSCS FY03.

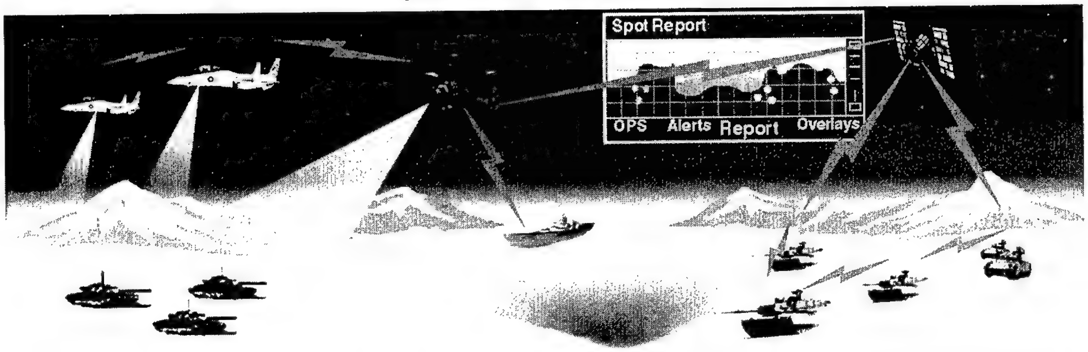
Auto data input and Force XXI battle command brigade and below data access to Global C^2 Sytsems—Army FY02.

SCHEDULE (Key Milestones)



Integrated Situation Awareness and Targeting ATD

(STO III.AV.1998.01)



Army Priorities

- Achieve information dominance in near and mid terms for total force.
- Achieve full-spectrum dominance in far term.
- Maintain combat overmatch.
- Recapitalize, extend equipment life, reduce cost of ownership.

Need for ISAT

- Provide real-time situation awareness capability to locate, identify, and target hostile forces and distribute this tactical information to network centric entities.

What is the problem?

Army air and ground vehicles lack:

- An integrated threat detection and warning suite for detection, acquisition, and hit avoidance measures.
- Critical real-time situation awareness necessary to survive and full spectrum of battlespace threats (RF/IR/EO guided weapons).
- Tactical electronic warfare (EW) data input to the global information grid (local SA).
- Smart deployment of ECM.

What are the barriers to solving this problem?

Laser warning receiver (LWR): beamrider signature identification and location, and designator and rangefinder signature identification and location.

Missile warning receiver (MWR): launch signature detection and location or origin.

On-/offboard data synchronization and distribution.

Multispectral fusion/correlation algorithms.

What is the product of this STO?

Hardware: form/fit/improved function modules for LWR, MWR, and radar warning receiver (RWR).

Software: tactical EW expert system.

Modeling and simulation: accredited high-level architecture tactical EW models.

What are the quantitative metrics?

Spatial (% range): RWR 4%–1%, MWR 10%, LWR 25%–10%

Temporal (second): RWR 20–5, LWR 20–10

Angular (degree): LWR 15°–5°

What is the warfighter payoff?

Provide air and ground warfighters combat overmatch through unprecedented real-time situation awareness from prevision onboard EW sensors.

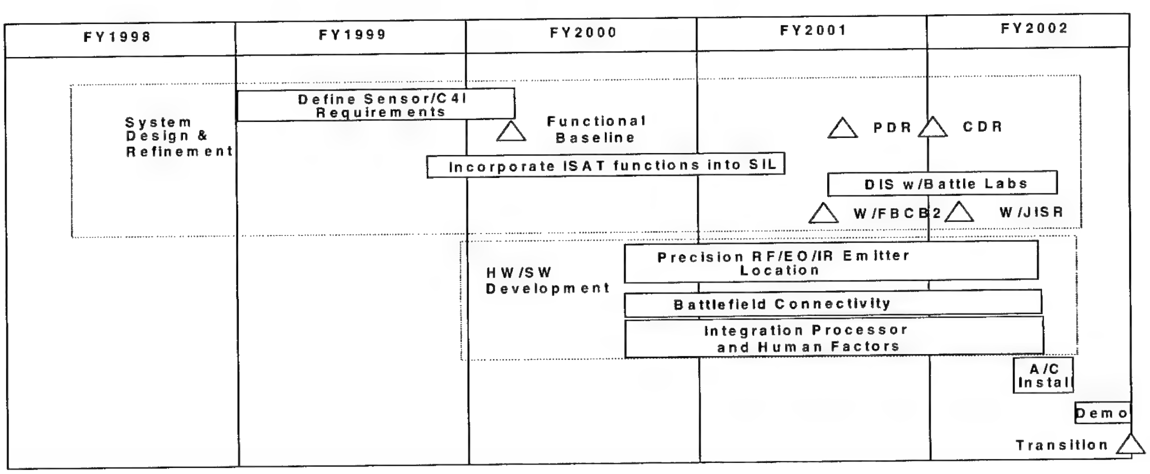
Reduced search volume reducing time to target.

Enhanced performance of EW systems via spares.

What are the transition milestones?

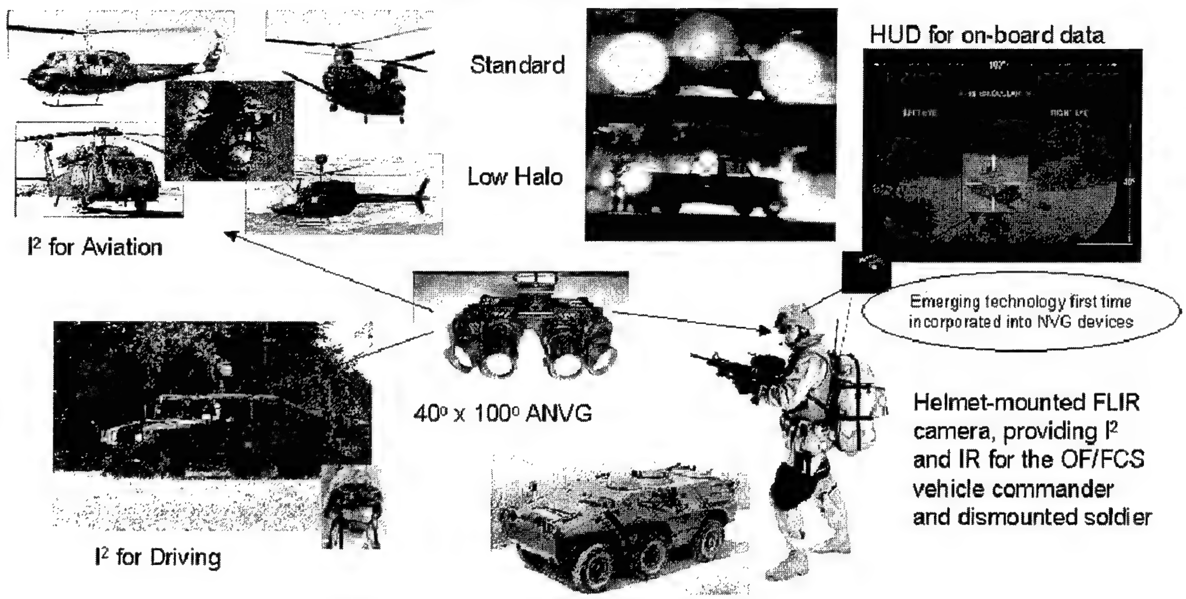
Transition through PM—Aircraft Survivability Sytems starting RDT&E funding lines starting FY03, Advanced Threat Infrared Countermeasure/Common Missile Warning System, Suite of Integrated RF Countermeasures.

SCHEDULE (Key Milestones)



Advanced Night Vision Goggles ATD

(STO III.AV.2000.01)



- Improved aviation situational awareness and safety with wider FOV
- Added IR target detection capability for Objective Force/FCS vehicle commanders and dismounted soldiers
- Integrated system of modular components provides enhanced mobility, safety, lethality, and survivability at minimum cost

What is the problem?

Current pilotage systems at 40° limit situation awareness and safety of flight.

Making the system cross compatible for all Army applications.

Image intensifier (I^2) has limited target acquisition capability.

What are the barriers to solving this problem?

Lightweight, wide field-of-fiew (FOV) optics.

High-performance, low-halogen I^2 tubes.

Integrated display, forward-looking infrared (FLIR).

IR cameras are too big and too expensive.

What is the product of this STO?

Wide FOV I^2 goggles (with helmet-mounted FLIR for mounted/dismounted soldier) to replace ANVIS and technology transfer to PVS–7s/14s.

System parameter studies, and simulator and operational test and evaluation.

What are the quantitative metrics?

Current achievable capability: 40°, 20/40 high-light (HL) and 20/120 low-light (LL) (ANVIS), 734 g, 2 AA, 30 hours.

Minimum acceptable capability: 40° × 100°, 20/30 HL and 20/85 LL, 734 g, 2 AA, 20 hours.

What is the warfighter payoff?

Improved situation awareness and safer pilotage with wider FOV and improved resolution.

Enhances operation in urban terrain with low-halogen capability. Added IR target detection capability for dismounted soldiers and vehicle commander.

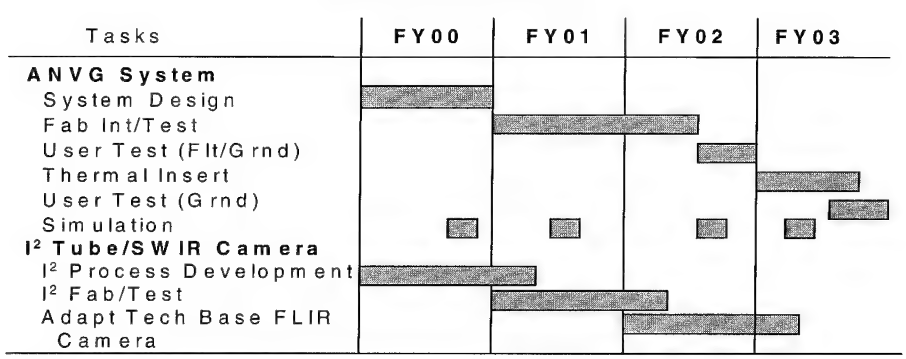
Horizontal technology integration approach for air and ground.

What are the transition milestones?

Transition to PM—Night Vision/Reconnaissance Surveillance and Target Acquisition in FY02.

Transition opportunity to high-performance ground applications, full I^2/IR in FY04.

SCHEDULE (Key Milestones)

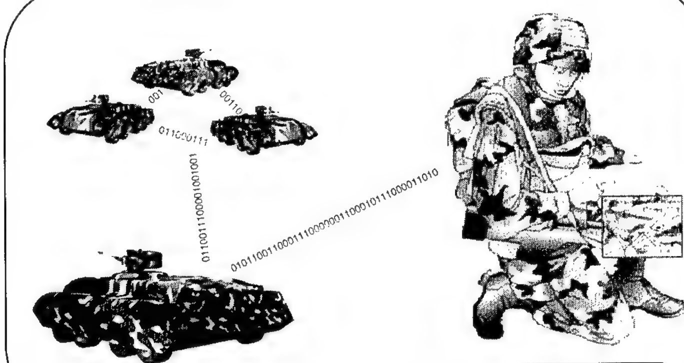


Agile Commander ATD

(STO III.C4.2000.01)

Demonstrate C^2, information, automation, and visualization technologies enabling a rapidly deployable, extremely agile, split-based headquarters with continuous battle planning and execution decision support

- **Collaborative C^2 planning tools**
- **Scalable, rapidly configurable, multi-role C^2 infrastructure linked to distributed enterprise information resources**
- **Profile-based, autonomous agent-driven "Battle Captain" supporting execution**
- **Communications network quality of service integration**



Characteristics

Common C^2 systems, multirole capability, lightweight, mobile, single or multivehicle, collocated or dispersed, stationary or on-the-move

What is the problem?

Current command and control (C^2) systems restrict the commander's battlefield mobility and do not support rapid assessment of battlespace information for decisionmaking.

What are the barriers to solving this problem?

Lack of automated C^2 planning and execution monitoring tools.

Limited access to distributed information/collaboration.

Inflexible, nonscalable C^2 systems.

Lack of sustainable C^2 on-the-move (OTM)

What is the product of this STO?

Rapid course of action (COA) generation, evaluation, and execution.

Virtual data warehouse with data management tools.

C^2 simulation/stimulation prototype environment.

Agile Commander/Multifunctional OTM Secure Adaptive Integrated Communications, Command, and Control interface model.

Mobile adaptive computing application.

What are the quantitative metrics?

Current: COA 2–3 hours, COA analysis (COAA)/wargaming 10–12 hours, execution monitoring to be manual.

Minimum: COA 1–1.5 hours, COAA/wargaming 5–6 hours, execution monitoring to be automatic for 100 events.

Goal: COA 5 minutes, COAA/wargaming 15 minutes, execution monitoring to be 1 minute for 300 events with alerts.

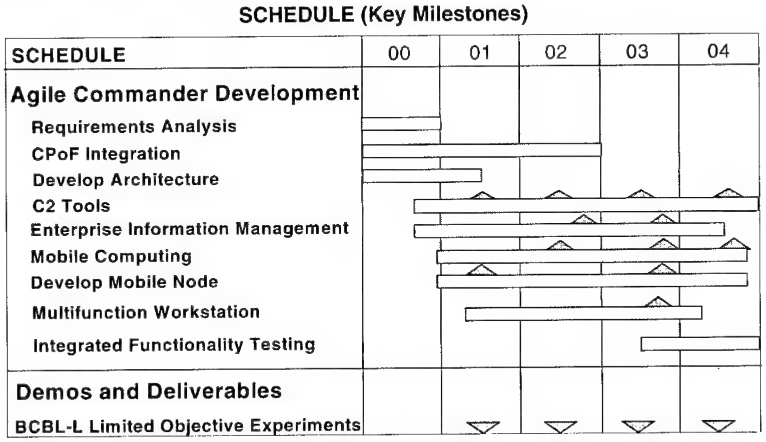
What is the warfighter payoff?

Mobile, integrated, distributed, command-centric, near-real-time, semiautonomous decision support system.

What are the transition milestones?

PM—Army Tactical C^2 System, PM—Common Software, PM—Field Artillery Tactical Data System (FY01–04).

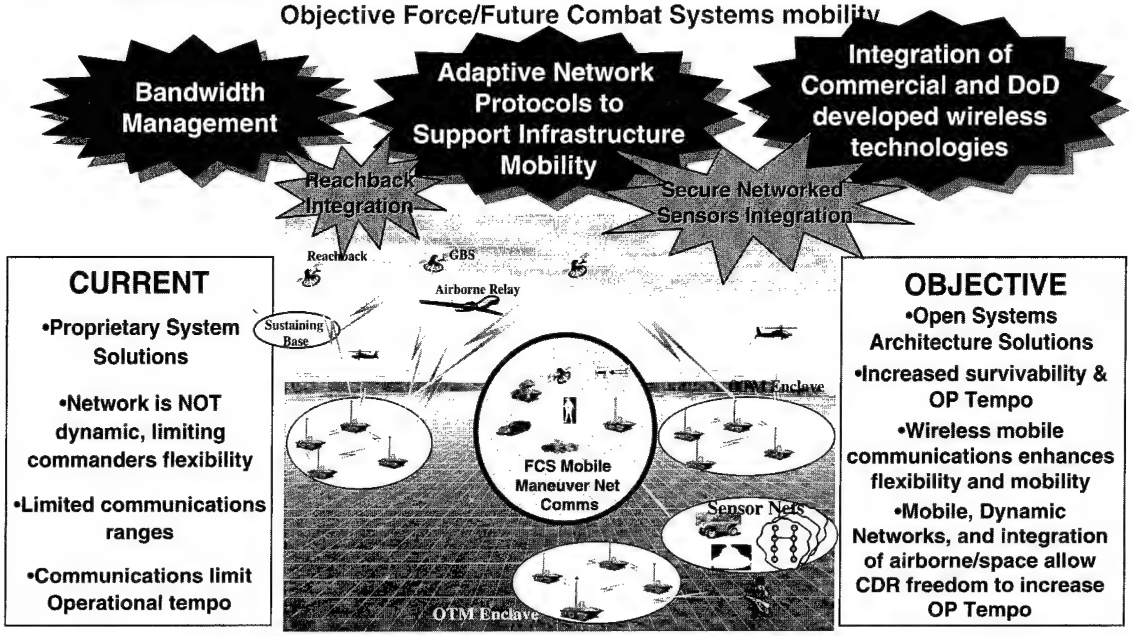
SCHEDULE (Key Milestones)



Multifunctional On-the-Move Secure Adaptive Integrated Communications ATD

(STO III.C4.2000.02)

Project Objective: To provide On-the-move Maneuver Net communications to support Objective Force/Future Combat Systems mobility



What is the problem?

Military communications infrastructure does not support a mobile geographically-dispersed battleforce for Objective Force and Future Combat Systems (FCS).

What are the barriers to solving this problem?

Lack of wireless communications protocols that support force mobility.

Lack of seamless internetworking of horizontal and vertical communications.

Lack of management of available wireless bandwidth.

What is the product of this STO?

Software protocols, agents + proxies to scale wireless bandwidth based on precedence, priority, or reservation, and support Internet protocol quality of service, ad hoc networking, and infrastructure mobility.

Integration of multiple wireless communications technologies into an open architecture solution.

What are the quantitative metrics?

Current capability: wired network, limited bandwidth, networks preconfigured, hours for setup and initialization.

Minimum capability: self-organized wireless 15–20 node cluster, ≤2-minute network installation, ≤5 minute network recovery, wireless on-the-move (OTM) network 56 kbps–15 Mbps (100 km to 100 m).

What is the warfighter payoff?

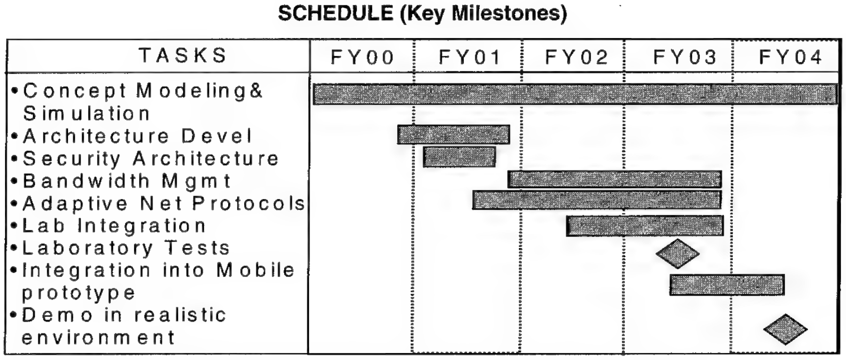
OTM mobile communications to support force mobility.

Increases OPTEMPO, flexibility, and survivability.

What are the transition milestones?

To PEO—Command, Control, and Communications Systems: Architecture solutions (FY01), wireless technology products (FY01, 03), ad hoc terrestrial-based protocols (FY02, 04), bandwidth mangement (FY03), and infrastructure mobility protocols (FY03, 04).

SCHEDULE (Key Milestones)



Crew Integration and Automation Testbed ATD

(STO III.GC.1999.02)

Driving Technologies
- Demo III Semi-Autonomous Driving
- Intelligent Driving Decision Aids
- Route Planning Decision Aids
- Drive-By-Wire

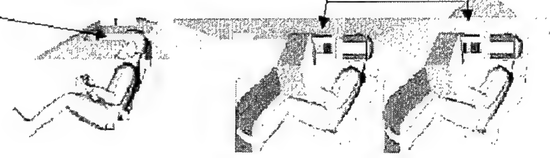
Two multi-role Crew Stations
- Commander/Driver
- Gunner

Evaluate both alternative positions of crew stations (I.e., front to back and side by side positioning and performing crew tasks and roles while operating a combat vehicle).

Advanced Electronic Architecture
- Advanced Network Technology
- Object Oriented Software Backplane

Onboard Safety Driver

Concept Vehicle Shown
- Actual vehicle selected will be C-130 transportable



MANPRINT
- IMPRINT workload/task analysis
- Human Figure Modeling
- Human Factors Crew Station Integration

Advanced Technologies
- Speech Recognition
- 3D Audio
- Indirect Vision
- Head Trackers
- Helmet Mounted Displays
- Crewman's Associate Interface

Embedded Simulation
- Embedded Training
- Mission Rehearsal
- Battlefield Visualization
- Command Coordination
- After Action Review

Impact on the Soldier: ***Optimize crew workload, allowing crews to more effectively perform their mission***

What is the problem?

Future Combat Systems (FCS) concepts require reductions in vehicle weight and volume that are not achievable with current crew sizes.

Increases in battlefield operational tempo (OPTEMPO) and required vehicle functionality have resulted in current crew station technologies being limited to combat vehicle war-fighter effectiveness.

What are the barriers to solving this problem?

Crew placement and time constraints for tasks.

Reconfigurable crew station for multiple combat roles.

Current architecture insufficient for automation requirements.

What is the product of this STO?

Advanced multirole crew stations with individual "vehicle transition ready" components, including intelligent driving decision aids, semiautonomous driving technology, automated route planning, and others.

What are the quantitative metrics?

Current capability: unique crew stations for each vehicle variant (TRL 3).

Minimum capability: single multirole crew station 100% of fight (19K), scout (19D), and carrier (11M) crew tasks (TRL 6).

Goal: single multirole crew station 100% of fight, scout, and carrier crew tasks and control unmanned aerial vehicle (UAVs) and unmanned ground vehicles (UGVs).

What is the warfighter payoff?

Enhanced performance and survivability of the crew.

Potential for reduced crew size (smaller, more transportble vehicles with lower logistics).

What are the transition milestones?

Transition into FCS via demonstration in FY04.

ATD will facilitate FCS Milestone B decision in FY06.

SCHEDULE (Key Milestones)

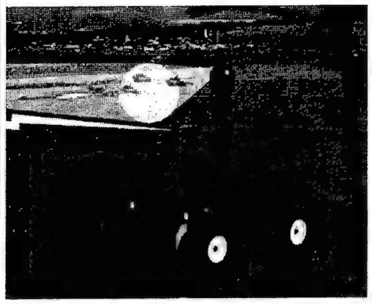
MILESTONE (FY)	00	01	02	03	04
Crew Task Analysis					
Complete design of crew station					
Develop refined embedded simulation technologies for on the move					
Modify semi-autonomous driving aids from DEMO III					
Investigate panoramic displays & helmet mounted displays					
Develop route planning and cognitive decision aids					
Conduct Warfighter Experiments (MMBL, SIL, & on vehicle)					
TRL Level		3		5	6

Robotic Follower ATD

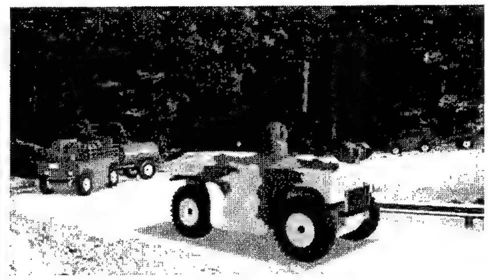
(STO III.GC.2000.04)

Objective: Demonstrate autonomous following capability providing reduced manpower and logistics for Future Combat Systems.

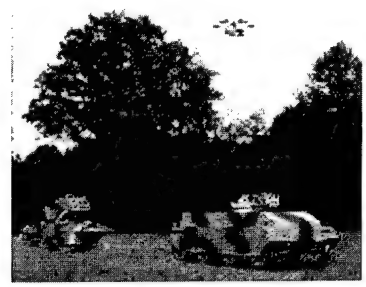
Ruck Sack Carrier



Rear Security



Convoy



NLOS/BLOS Fire

Pacing Technologies:

- **Object detection/avoidance sensors and software algorithms**
- **Software algorithms for collision avoidance**
- **Autonomous following software algorithms**
- **Navigation following**

Warfighter Payoffs:

- **Increased survivability**
- **Increased lethality**
- **Decreased logistics burden**
- **Decreased manpower requirements**

Provides Near-Term Unmanned Capability to Meet User Needs

What is the problem?

Current robotic technologies lack battlefield mobility, speed, and robustness for Objective Force applications.

What are the barriers to solving this problem?

Autonomous technology capability projections do not meet FCS requirements

Unmanned systems following manned vehicles with significant physical or temporal separation.

Detecting new obstacles in the follower's path.

What is the product of this STO?

15 April 03: Follower algorithms and experimental data GFI to PM–FCS.

15 April 04: Follower demonstrators and advanced performance algorithms GFE/GFI to PM–FCS.

FY05: Follower demonstrator with mission equipment package (MEP).

What are the quantitative metrics?

Current achievable capability (TRL 3): low speed follower (15 kph offroad) with 500-m separation.

Minimum acceptable capability (TRL 6): 30-kph offroad follower at 160-km separation.

Goal (TRL 6): 65-kph offroad follower at 750-km separation.

What is the warfighter payoff?

Decreased logistics burden, decreased manpower requirements, and increased mobility and operational tempo (OPTEMPO).

Reduced force footprint.

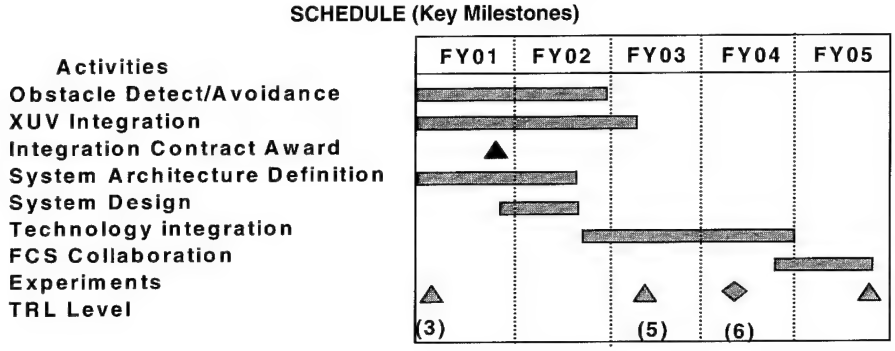
What are the transition milestones?

Algorithms transfer to FCS in FY03.

Demonstrators GFE to FCS in FY04.

Collaborative efforts with FCS in FY05 to integrate MEP and transition software.

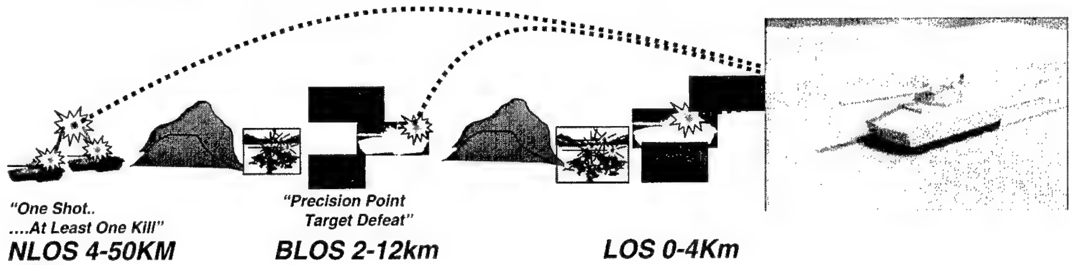
SCHEDULE (Key Milestones)



Multirole Armament and Ammunition ATD

(STO III.WP.1999.01)

Objective: Demonstrate compact, direct/indirect fire armament system module capable of rapid lethality against the full spectrum of threats at 0-50km range.



Pacing Technologies:

Cannon -
- **Recoil Mitigation**

Munitions -
- **Electro-Thermal-Chemical Propulsion**
- **Seeker/Guidance & Control**
- **Multi-Mode Warhead**

Warfighter Payoffs:
- **Heavy Force Lethality With a 105mm**
  - **> Multi-range - LOS, BLOS, & NLOS**
  - **> Multi-Threat Capable**
- **Reduced logistic footprint**
  - **> High Number of Stowed Rounds**

A Lightweight Armament System For Dominating the Red Zone and Beyond

What is the problem?

Need for a multirole, lightweight Future Combat System (FCS) integrated multifunctional armament system and ammunition suite that provides robust defeat of the threat spectrum in "Red Zone" and tactical deep engagements, 0–50 km, with a reduced logistics footprint.

What are the barriers to solving this problem?

Low impulse/lightweight integrated launcher with high rate of fire; versatile propulsion system for various munition packages; LOS rapid defeat of future heavy armors (0–4 km); TLE reduction while maintaining affordability; extended range with reduced cartridge volume/weight; smaller warheads retaining/increasing antiarmor performance with increased lethality for other targets

What is the product of this STO?

Integrated multirole, lightweight FCS armament system and ammunition suite; lightweight, low-impulse launcher demonstrator with ETC igniter; advanced KE cartridge—LOS fire (0–4 km) against heavy armor; MP–ERM—LOS/NLOS (2–12 km) against spectrum of threat; Smart Cargo Projectile—BLOS/NLOS support (4–50 km) enables counterfire, suppression, and interdiction missions

What are the quantitative metrics?

Weapon Recoil Force (lbs–f): current 160 K, minimum 100 K, goal 85 K

Gun Weight (lbs): current 6,700; minimum 3,500; goal 2,900

KE Penetration at 4 km: current M829A2, minimum A2+50%, goal A2+70%

MP–ERM—BLOS/PSSK: current none, minimum PSSK (class), goal at 8+ km

Cargo Pay/Vol Ratio: current 40%, minimum 50%, goal 70%

Warhead—SC L/D: current 1.7, minimum 1.0, goal 0.8

EFP Pen Increase: current (class) 0%, minimum +25%, goal +40%

Start TRL: Arm 4/5, KE & MP–ERM 4, Cargo and End TRL 7

What is the warfighter payoff?

Engage and kill by LOS, BLOS, and NLOS fires with first round effects on target, increased stow kills per weapon; robust direct fire defeat capability against future threat armor; reduced ammunition logistic tail; multipurpose warhead lethality against spectrum of threat; simplified armament system and munition logistics; reduced deployment footprint

What are the transition milestones?

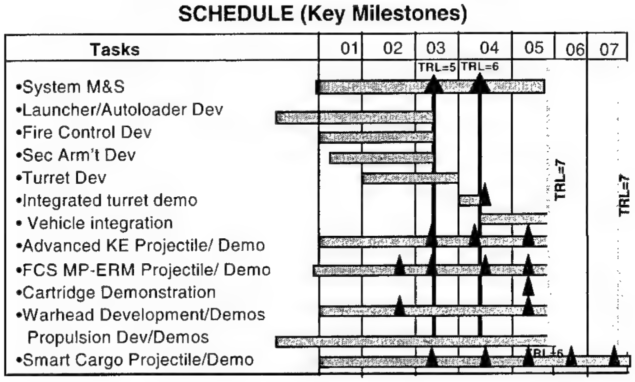
FY04: Armament Mission Module to DARPA contractor

FY05: Advanced KE and MP–ERM integrated DARPA demonstration

FY06: FCS SDD decision, add KE and MP–ERM

FY08: Smart Cargo Block Upgrade transition to SDD

SCHEDULE (Key Milestones)



ANNEX

C ADVANCED CONCEPT TECHNOLOGY DEMONSTRATIONS

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In early 1994, DoD initiated the Advanced Concept Technology Demonstration (ACTD) program designed to expedite the transition of maturing technologies from the developers to the users. This program speeds technology to the warfighter. ACTDs emphasize technology assessment and integration rather than technology development. The goal is to provide a prototype capability to the warfighter and to support him in the evaluation of that capability. The warfighters evaluate the capabilities in real military exercises and at a scale sufficient to fully assess military utility.

ACTDs exploit mature and maturing technologies to solve important military problems. A primary objective of an ACTD is to rapidly transition new capabilities from the developer to the user. ACTDs are especially applicable when an answer to a military problem is not known ahead of time. ACTDs allow the user and materiel developer to jointly experiment with the application of technologies and new operational concepts in the field environment prior to committing to formal acquisition.

ACTDs are designed to allow users to gain an understanding of proposed new capabilities for which there is no user experience base. Specifically, they provide the warfighter an opportunity:

- To develop and refine his concept of operations to fully exploit the capability under evaluation.
- To evolve his operational requirements as he gains experience and understanding of the capability.
- To operate militarily useful quantities of prototype systems in realistic military demonstrations and, on that basis, make an assessment of the military utility of the proposed capability.

By limiting consideration to mature technologies, the ACTD avoids the time and risks associated with technology development, concentrating instead on integration and demonstration activities. This approach permits an early user demonstration on a greatly reduced schedule at a reduced cost. The potential or projected effectiveness must be sufficient to warrant consideration of an ACTD, or the capability must address a need for which there is no suitable solution.

ACTDs are sized and structured to provide clear evaluation of military capability. The user, with support from the operational test agencies, defines the measures of effectiveness and measures of performance that characterize the desired capability and suitability. Data collection is tailored accordingly. The quantity of systems in the ACTD is sufficient to provide a valid assessment of the capability, or simulations are used to expand the battlespace and forces involved in the exercise. The user provides, or at least approves, the planned operational exercises that typically include both red and blue forces.

Many of the ACTDs are based on advanced technologies that may permit, or even demand, new CONOPS, tactics, and doctrine in order to realize their maximum potential. The ACTD provides

a means to develop, refine, and optimize these warfighting concepts to achieve maximum utility and effectiveness.

A key goal of ACTDs is to move into the appropriate phase of formal acquisition without loss of momentum, assuming the user makes a positive determination of military utility. Each ACTD has a clear acquisition goal for the post-ACTD phases. In addition, there must be provisions for the development of formal operational requirements; documents addressing interoperability, life-cycle cost, manning, and training; and preparations for supportability.

The ACTD Master Plan describes the rationale and objectives of the ACTD program. It provides the OSD guidance regarding the processes for proposing, selecting, managing, and transitioning ACTDs.

Army ACTDs are nominated by HQ TRADOC, forwarded to HQDA, who then submits formal Army nominations to OSD. OASA(ALT) is the Executive Agent for Army ACTDs; they are coordinated closely with ODCSOPS. An Army materiel developer serves as the ACTD technical manager, the appropriate Army material developer serves as the transition manager, and TRADOC is a member of the ATCD management team. At the conclusion of the ACTD operational demonstration, there are three potential outcomes. The user sponsor may recommend acquisition of the technology and fielding of the residual capability that remains at the completion of the demonstration phase of the ACTD to provide an interim and limited operational capability. If the capability or system does not demonstrate military utility, the project is terminated or returned to the technology base. A third possibility is that the user's need is fully satisfied by fielding the residual capability that remains at the conclusion of the ACTD, and there is no need to acquire additional units.

ACTD candidates are evaluated by several key criteria—response to user needs, maturity of technologies, and potential effectiveness. ACTDs focus on addressing critical military needs. To evaluate proposed solutions to meet these needs, intense user involvement is required. ACTDs place mature technologies in the hands of the user and then conduct realistic and extensive military exercises to provide the user an opportunity to evaluate utility and gain experience with the capability. The process provides the users a basis for evaluating and refining their operational requirements, for developing a corresponding concept of operations, and ultimately for developing a sound understanding of the military utility of the proposed solution before a decision is made to enter into the formal acquisition process. Furthermore, a key objective of ACTDs is to provide a residual operational capability for the warfighter as an interim solution prior to procurement.

Differences Between ATDs and ACTDs. ATDs are intended to demonstrate the maturity of a technology. The demonstrations are conducted with a TRADOC battle laboratory in a representative operational environment. ACTDs are intended to demonstrate the military utility of mature technologies and provide a means for determining whether to pursue an acquisition program. ACTDs include a sponsoring user/CINC, the demonstrations are conducted in an operational environment, and the ACTD provides 2 years of residual support for the prototype systems provided to the user/CINC.

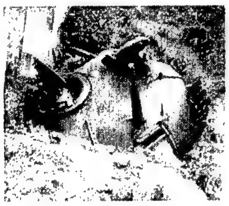
Army ACTDs: The Army has seven S&T-funded ACTDs in FY01, and several candidates competing for approval as FY01 new-start ACTDs. Descriptions of the current Army S&T-funded ACTDs follow.

Line-of-Sight Antitank ACTD

(STO III.WP.1998.01)

LOSAT provides Forced / Early Entry Forces a Decisive Edge

SIGNIFICANT LETHALITY OVERMATCH



Defeats Active Protection Systems and Explosive Reactive Armor

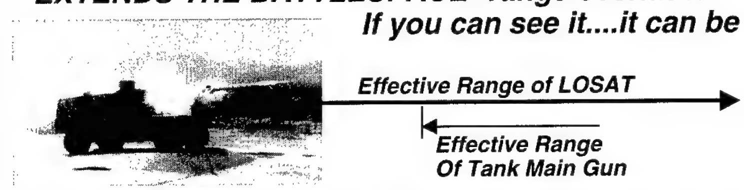
RAPID RATE OF FIRE

Advanced Fire Control S/W - Multiple Threat Auto Tracking

- ***Started in FY98***
- ***CENTCOM Sponsor***
- ***Demo Phase Completes in FY03***
- ***Residuals:***
- ***144 Missiles***
- ***12 Fire Units***

EXTENDS THE BATTLESPACE--range overmatch

If you can see it....it can be killed!



Target ID & Accuracy Beyond Threat Engagement Ranges

Looks like a HMMWV, kills like a Tank

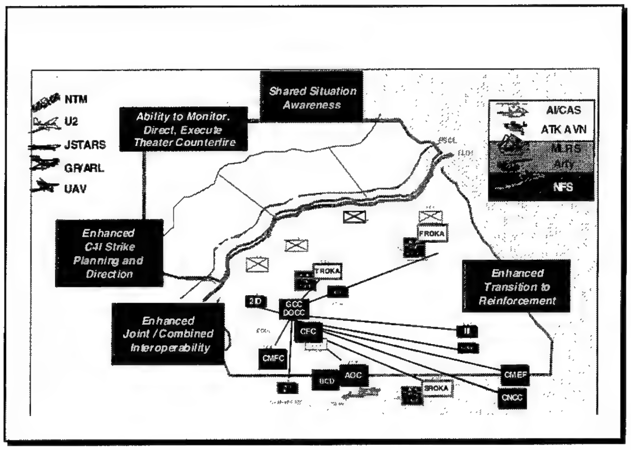
The objective of the LOSAT ACTD is to evaluate the military utility of the LOSAT system and the degree of improvement in the operational capabilities of light forces conducting forced/early entry operations when provided a deployable assault support/anti-armor weapon system capable of defeating high-value targets, including heavy armor and bunkers.

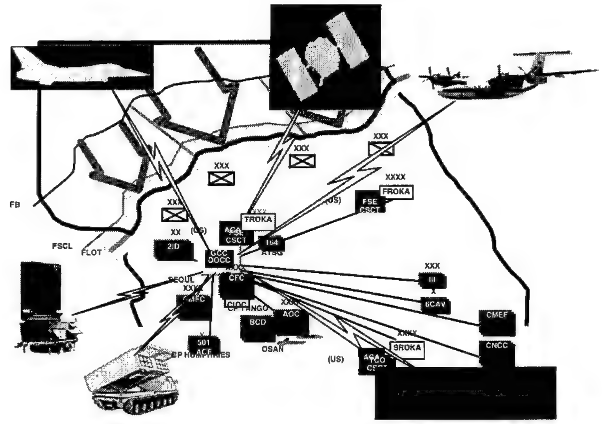
LOSAT consists of an expanded-capacity HMMWV, hypervelocity kinetic-energy missiles, and a second-generation forward looking infrared/TV acquisition system. The LOSAT system carries four ready-to-fire missiles via two 2-pack launch pods. A rapid rate of engagement and over-matching KE lethality, together with a time of flight to maximum range of less than 5 seconds, make the system highly countermeasure resistant to current and future armor, including those with Active Protection Systems (APSs). The LOSAT system provides enhanced lethality against high-value targets, including heavy armor and bunkers. The digitized C^2 capability of this system is compatible with the Army's digitization efforts, making it a viable system well into the 21st century.

The LOSAT ACTD, given a positive assessment of military utility at the end of the demonstration period, will result in an operational LOSAT company with 144 missiles, integrated into the C^2 structure of the XVIII Airborne Corps in 4QFY03.

Theater Precision Strike Operations ACTD

(STO III.C4.1998.01)

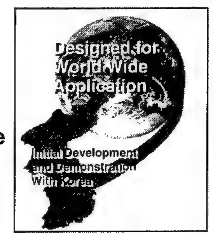




- *Started in FY98*
- *Addressing Joint C4I Interoperability*
- *GCC-ACC-NCC Synchronization*
- *Planned Residuals:*
  - *Firefinder Networking*
  - *DOCC Automation/Integration with ABCS/GCCS/LAWS/TBMCS*

Mission

Provide the CINC With a Significantly Improved Capability to Plan and Direct Theater Counterfire and Precision Strike Operations through the Real Time Synchronization of US/Coalition Assets FLOT to Forward Boundary



"The JPSD Theater Precision Strike Operation Initiative is Key to Providing the CINC and his Component Commanders with Situational Awareness and the Ability to Focus the Theater's Warfighting Potential." -GEN John H Tilelli, CINC, USFK

The Military Need. The Army's role in supporting this CINC requirement focuses on the C^2 capabilities at the theater army/ground component command (GCC) level. At this echelon, critical requirements will be serviced by the newly authorized Army service component command (ASCC). Within the ASCC's operations center, the deep operations coordination center (DOCC) is charged with managing deep operations and the counterfire fight within the GCC AOR. The DOCC must quickly gather and share intelligence and targeting information, determine enemy courses of action, plan and orchestrate operations, allocate and request resources, and monitor the execution of deep operations.

The TPSO Response to the Need. The TPSO mission is to provide the CINC with a significantly improved capability to plan and direct theater counterfire and precision strike operations through the real-time synchronization of U.S./coalition assets. TPSO addresses this urgent need by applying mature technologies to enhance the Joint and Combined C^4I and strike planning processes at the theater level. Attaining this objective will permit the commander to see the battle, focus his warfighting assets to shape the battlefield, and influence the outcome to achieve his objectives. Enabling objectives of the TPSO ACTD are:

- Enhance C^4I/strike planning process.
- Enhance joint and combined interoperability.
- Enhance transition to reinforcement.
- Provide a venue to demonstrate integration of externally funded weapon systems/JTTPs.

Military Operations in Urbanized Terrain ACTD

(STO III.SH.1997.01)

Improve the Operational Capabilities of Soldiers and Marines in a MOUT Environment

- Joint Army/Marine Corps/Started in FY 98
- Completes FY02
- Multiple Joint Experiments
- COTS/GOTS solutions
- New TTPs (8 handbooks - Indivdual thru Bn individual and collective MOUT tasks)
- Advanced Concept Excursion for emerging/ post ACTD S&T for MOUT
- Culminating Battalion Level Demo at JRTC Sep 00 during JCF AWE
- Transition Highlights
    - TTPs to XVIII Airborne Corps/Land Warrior EXFOR
    - Facilities for training/experimentation
    - RLEM WRAP with PM Small Arms
    - FY01 SEP: blunt training munitions
    - FY01 MEP: mechanical breaching
    - Shark Headset to Land Warrior
    - Modified USA/USMC body armor ORD

Quikstep Ladder

Rafael Simon Breaching Round

Firing Rafael Breaching Round

Pointer UAV

DEM-TEK Breach Tools Kit

The objective of the joint Army/Marine Corps MOUT ACTD is to improve the operational effectiveness of soldiers and marines operating in MOUT. The objective of the MOUT ACTD has been developed into a three-part mission: (1) determine the military utility of advanced technologies and new operational concepts to achieve dominance in MOUT go-to-war operations, (2) provide interim operational capabilities to the MOUT ACTD experimental unit(s) with associated tactics, techniques and procedures (TTPs), and (3) set the stage for rapid acquisition of the successful ACTD products.

Urban centers have increasingly become the sites of conflict throughout the world, and will remain so as we move into the 21st century. The nature and complexity of the urban environment mandates manpower-intensive operations due to line-of-sight restrictions, inherent fortifications, limited intelligence, densely constructed areas, the presence of noncombatants and associated restrictive rules of engagement. These manpower-intensive operations have a much higher potential for casualties and collateral damage than operations in other environments. The Marine Corps requirements for MOUT operations stem from the *Defense Planning Guidance* for FY 1998–2003, the *Marine Corps Master Plan for the 21st Century,* and *Mission Area Analysis #21*, dated 19 September 1995 (deficiency 17).

To focus the ACTD on providing solutions to the military need, the Army and Marine Corps have developed 32 joint operational requirements specifically identifying the operational deficiencies experienced by soldiers and Marines in past operations, such as those in Grenada, Panama, Somalia, and Haiti. The requirements are rooted in the four primary functional areas of

focus of the ACTD, which are based on input from both services and CINCs: C^4I, engagement (lethal and nonlethal), force protection, and mobility.

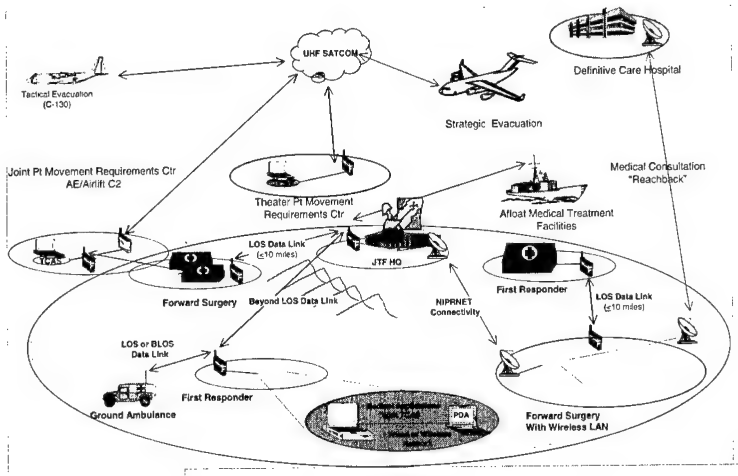
An ongoing technology assessment process will identify and select candidate technologies to address the joint MOUT operational requirements. The operational effectiveness of candidate technologies and supporting TTPs will be determined by modeling and simulation and through a series of Army and Marine Corps live experiments ranging from squad level to platoon level. A capstone, battalion-level joint Army/Marine Corps demonstration was conducted by the XVIII Airborne Corps and the 2d Marine Division MCSFLANT at the Joint Readiness Training Center. Technologies that demonstrate significant operational effectiveness during the demonstration will become interim capabilities and will be supported for 2 years. The post-ACTD plan to acquire the capability across the force will be developed as part of the ACTD.

Joint Medical Operations—Telemedicine ACTD

(STO III.ME.1999.02)

Tailored for Deployment by the JTF Commander

- **Outpatient Support and Data Capture at Forward MTFs**
- **Placeholder for the TMIP Interim Theater Data Base (ITDB)**
- **Modeling and Simulation, Mission Rehearsal Packages**
- **Medical Lifeline Reach-back Package**



•Started FY99
•CINC PACOM Sponsor
•Completes FY02
•Planned Residuals:
- Modeling & Simulation Tools
- Deployable HW/SW/Comms Sets
- Theater Telemedicine Team

Theater-wide Joint Medical Information Superiority

The concepts of full-dimensional protection and focused logistics described by *Joint Vision (JV) 2010* pose significant challenges to force health protection and medical support. Full-dimensional protection requires awareness and assessment of deployed forces as they execute their missions. Enemy hostilities pose the greatest threat to life, diseases and nonbattle injuries (DNBI) remain the single greatest detriment to effectiveness.

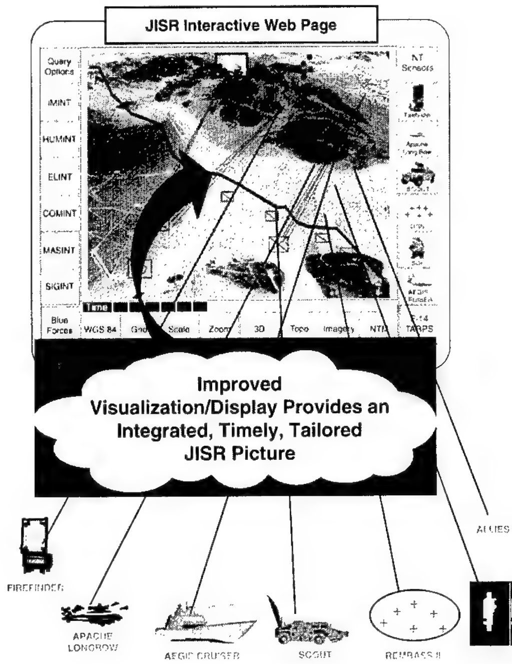
The goal of this ACTD is to provide the medical capabilities that support concepts put forth by the Chairman, Joint Chiefs of Staff, in JV 2010. This ACTD will provide warfighting CINCs a near-term capability to defeat time, distance, and organizational obstacles to effective joint health service support in austere and nonlinear operational environments. Significant improvements are necessary in medical communications, information management, planning and rehearsal, and forward-deployed medical capabilities. Joint Medical Operations–Telemedicine focuses on technologies providing a functionally integrated capability that includes forward echelon medical telepresence, better medical collaborative planning tools, information superiority, and net-centric communications. Novel modeling and simulation tools will permit planners to tailor deployed medical capabilities and provide mission rehearsal opportunities. Achieving these medical support capabilities demands an improved ability to project, virtually, theater-wide and worldwide medical knowledge into the tactical battlespace, to acquire and provide the right data and information to ensure superior knowledge of the medical battlespace in real time, and to employ that knowledge effectively in planning and executing joint medical operations.

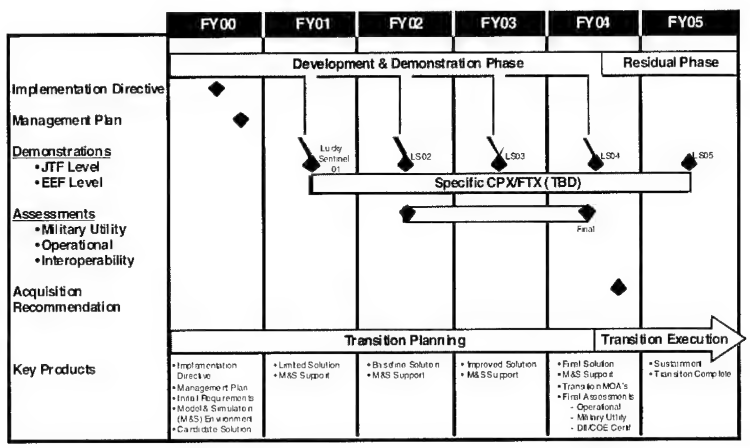
The Joint Medical Operations–Telemedicine ACTD was the result of a development partnership between Army/Navy/Air Force technology developers and the CINCPAC Surgeon, and service combat systems developers. The JMO-T ACTD is sponsored by the U.S. Pacific Command in two major demonstrations, one in FY99 and one in FY00. Demonstration I was conducted in two exercises, Kernel Blitz 99 (KB99) and Patriot Medstar 99 (PM99). Demonstration II was held during a FY00 capstone exercise, Cobra Gold, May 2000.

Joint Intelligence, Surveillance, and Reconnaissance ACTD

(STO III.IS.1999.02)

Bridge the Gap in Situational Awareness Between Operational and Tactical Forces





The goal of the Joint Intelligence, Surveillance, and Reconnaissance (JISR) ACTD is to implement an Internet web technology-based system-of-systems that integrates existing C^4ISR sensors and processors to establish a joint tactical sensor grid. This sensor grid will seamlessly integrate with existing theater C^2I architecture to provide timely and relevant sensor data and other intelligence information to early entry forces and their supporting headquarters.

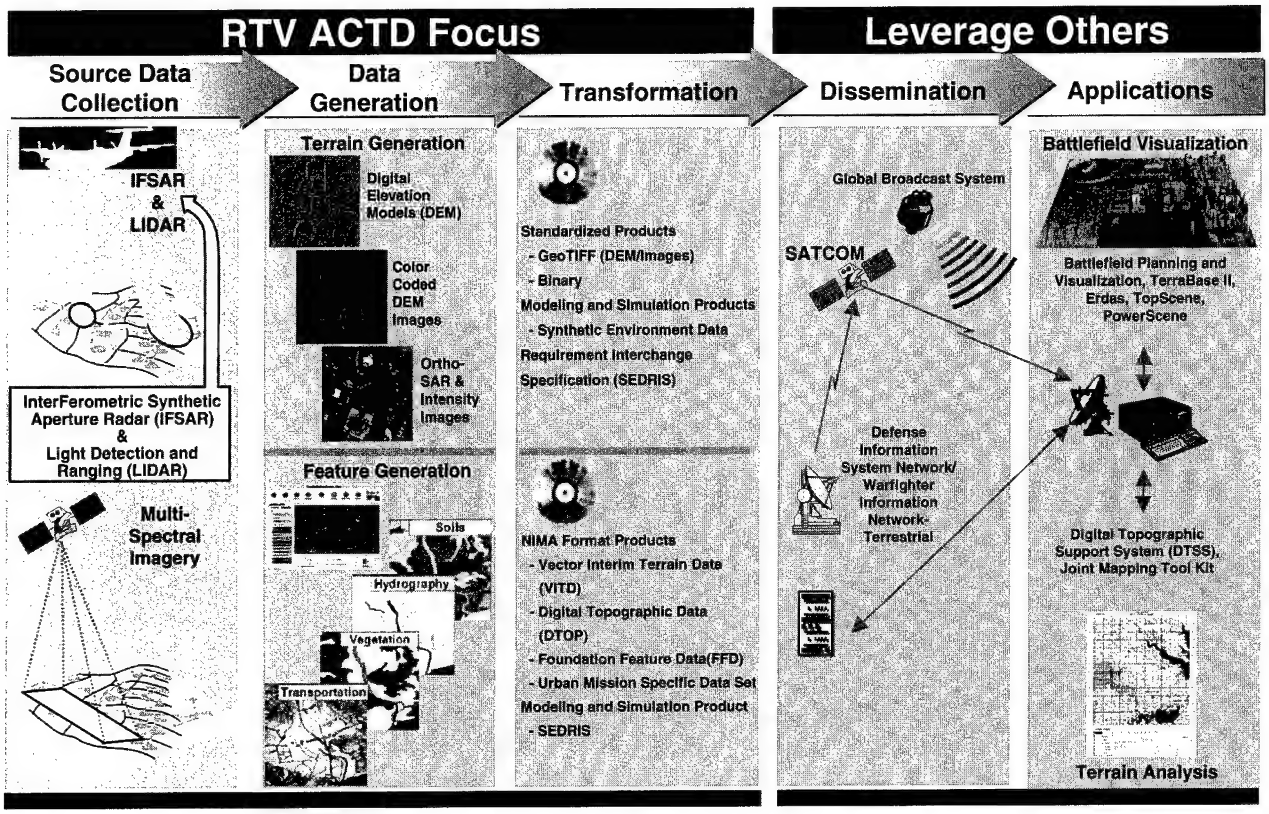
The 1998 Defense Science Board Summer Study "Joint Operations Superiority in the 21st Century" deemed this area a critical operational requirement.

The CINC, U.S. Central Command identified an urgent priority to provide timely top-down/bottom-up ISR and operational information and enhanced battlespace visualization for the EEF commander. This includes the need to share that picture with the joint task force and coalition partners.

The JISR ACTD will develop the capabilities to provide early entry forces and their supporting headquarters with significantly improved situational awareness by means of more effective and timely access, integration, and visualization of relevant multi-service multiechelon ISR information.

Rapid Terrain Visualization ACTD

(STO III.EN.1996.01)



The RTV ACTD objective is to:

- Demonstrate the technologies and infrastructure to meet the Army requirement for rapid generation of digital topographic data to support emerging crisis or contingencies.
- The RTV ACTD will include tradeoff studies of the military utility of various digital terrain elevation data (DTED) levels of resolution related to specific missions, areas of interest, and responsibility. Information obtained from these studies will be provided to TRADOC for use in refining Army requirements for high-resolution DTED.

Future conflicts will likely involve U.S. forces in regions not previously considered hostile and lacking topographic data, where indigenous forces will have the most comprehensive and accurate knowledge of the terrain. U.S. forces require timely and comprehensive digital topographic data (DTD) to counter this disparity. The RTV ACTD will demonstrate the technologies and infrastructure to rapidly provide DTD. These technologies include computer hardware, software, displays, networks, automatic target recognition capabilities, sensors, and terrain databases. Significant investment by industry and government has resulted in the rapid progression of most of these technologies. However, one fundamental capability was not progressing—the ability to rapidly collect high-resolution terrain data. The Army would not have the high-resolution terrain databases it needed unless additional focus and resources were applied. In addition, there was no clearly focused program to rapidly integrate the key technologies and transition them to the warfighter in the near future.

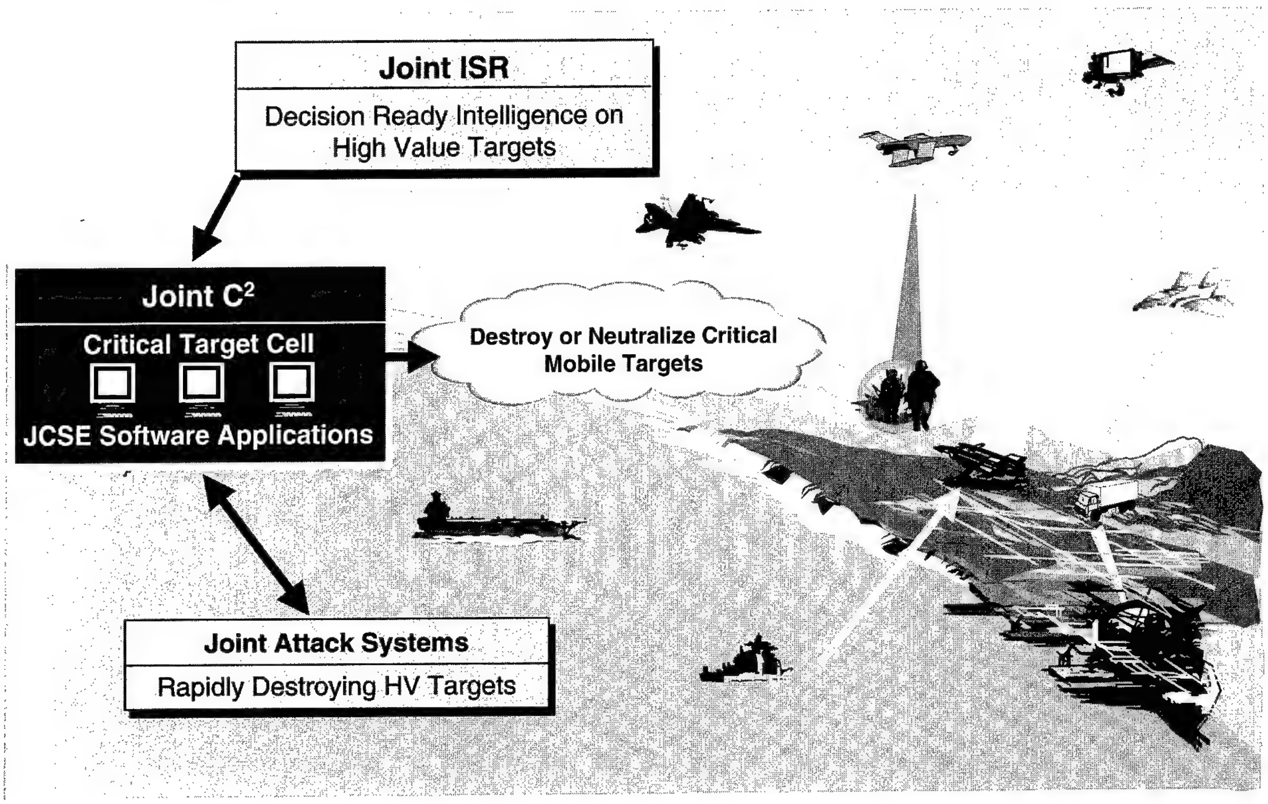
The Joint Precision Strike Demonstration Project Office developed a concept for an RTV ACTD, approved by the Deputy Under Secretary of Defense for Advanced Technology for a 5-year program beginning in FY97. The XVIII Airborne Corps at Fort Bragg was designated as the primary user. The Joint Requirements Oversight Council gave the highest priority to the RTV ACTD.

The Army has identified area coverage and timeliness requirements for DTD to support crisis response and contingency operations. DTD include DTED, feature data, and imagery. The area coverage and timeliness requirements for DTD are 20- by 20-km area in 18 hours, 90- by 90-km area in 72 hours, and 300- by 300-km area in 12 days.

The resolution requirement for DTED is Level III (10-m grid spacing) over the entire area of interest with several smaller inserts containing higher resolution data with grid spacing ranging from 3 m (DTED IV) to 1 m (DTED V).

DoD does not currently have the requisite capabilities to rapidly collect and process DTD. DTD are the foundation for the common picture of the battlefield that will be embedded in all C^2 systems. The Army requires DTD to support intelligence preparation of the battlefield, mission planning, mission rehearsal, wargaming, and execution monitoring. High-resolution data will also be used for more accurate target geolocation and will be essential in future weapon platform's navigation, targeting, and sensor systems.

Joint Continuous Strike Environment ACTD



The fundamental purpose of the JCSE ACTD is to introduce a series of nested loops into service, joint, and combined targeting cycles that reduces, by at least one order of magnitude, the latency associated with correlating command guidance, weapons, targets, and airspace deconfliction. JCSE will optimize the weapons by providing the software glue to automatically combine actionable targets emerging from the ISR processing exploitation and dissemination path with command objectives. JCSE then supplies weapon status information both horizontally and vertically across a JFC's organization allowing commanders to pair weapons with targets based on availability rather than organizational ownership.

Although major advances in surveillance technology and kill mechanisms are entering the force structure, these assets are controlled using 1970s-era information technology. Development, integration, and transition of technology for mass precision strike have been uneven. Consequently, time-critical surface targets continue to operate inside U.S. strike cycles. The JCSE ACTD seeks to address this at the component, joint, and coalition levels.

Emergent targets are high-payoff land and maritime platforms, force groupings, and geographic complexes that must be attacked inside cycle times that are not consistently achievable by the current joint targeting process. Emergent targets demand a seamless flow of information across service, organization, and system boundaries if they are to be consistently serviced within their short windows of vulnerability (1 to 2 hours or less). Numerous studies have documented the latency introduced in to the targeting process when data have to be rekeyed, air gapped, or disseminated in hard copy.

JCSE consists of software that will augment and advance service, joint, and combined fire support systems. During the course of the ACTD, JCSE functionality will be demonstrated in a series of joint and combined exercises employing deep strike assets from all services and selected allied assets.

ANNEX

D LOGISTICS

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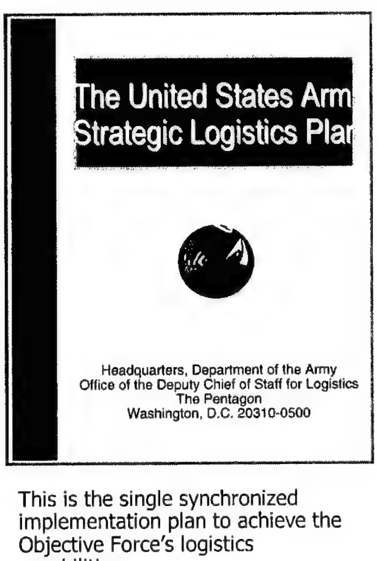
D LOGISTICS

CHALLENGE AND OPPORTUNITY

Senior Army leaders have concluded that the Army must transform to meet its current, emerging, and future strategies and missions. They have also determined that the new combat systems developed and procured for this transformation must be rapidly deployable, lighter in weight, more lethal, and more reliable. They must have a vastly reduced demand for logistics support. A significant percentage of the strategic lift requirements are consumed by deploying required logistics. The Army needs technologies to reduce the logistics footprint deploying with the combat force.

We will aggressively reduce our logistics footprint and replenishment demand. This will require us to control the number of vehicles we deploy, leverage reachback capabilities, invest in a systems approach to weapons and equipment we design, and revolutionize the manner in which we transport and sustain our people and materiel.

—The Army Vision



This is the single synchronized implementation plan to achieve the Objective Force's logistics capabilities.

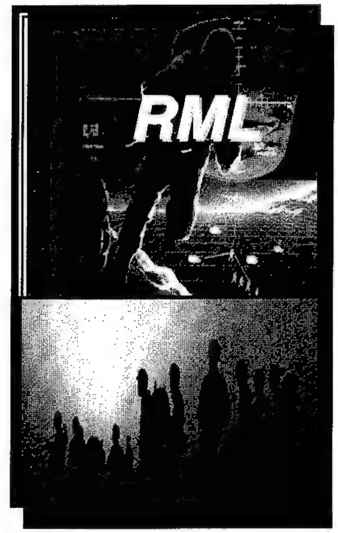
FIGURE D–1. ARMY STRATEGIC LOGISTICS PLAN

This annex is organized in four sections: (1) challenge and opportunity, (2) Combat Service/Combat Service Support (CS/CSS) Transformation technology areas, (3) logistics demand reductions enabled by technology demonstrations, and (4) logistics opportunities possible through advances in Strategic Research Objectives (SROs).

Closely tied to the goals of *The Army Vision* and the transformation strategy to achieve it is the CS/CSS Transformation, which builds on the baseline established by the RML. The *Army Strategic Logistics Plan* is the Army's roadmap to achieve CS/CSS Transformation (Figure D–1). Central to this transformation is the need to change CS/CSS processes and systems; specifically, enhance deployment, reduced the logistics footprint in the battlespace, and reduce the total cost of logistics without jeopardizing combat capability.

To achieve this, logistics demand reduction innovation from the S&T community is needed to design out the demand through engineering. A key component of CS/CSS Transformation is this strategy of engineering out logistics demand in the FCS and other future combat systems. Examples include reduced fuel consumption, ultra

reliable parts, corrosion prevention. self-healing materials and systems, built-in-test (BIT) systems, and built-in real-time prognostics. Currently fielded weapon systems required the deployment of test sets, large quantities of spare parts, and tools and special tools to effect repairs on components that fail during the deployment. Logistics requirements on the battlefield are directly proportional to the demand for logistics designed into our combat equipment. The mean time between failure (MTBF) of combat equipment component systems dictates the number of personnel trained to make the repairs, vehicles and communication assets to respond to repair requirements, and all the associated care, feeding, and protection of the repair personnel and the associated supply, transportation, and other support personnel and equipment. Designing out the demand for support is essential to providing a strategically deployable force that retains its combat effectiveness on the battlefield.



The *Revolution in Military Logistics* (RML), published in 1998, details the capabilities, business process reengineering, and guidance required by the logistics community to meet the goals of the Objective Force

Several compelling reasons to design out demand by incorporating new technologies into future combat equipment include:

- It would enhance the capability to meet the new deployment timeline goals—one brigade, 96 hours; one division, 120 hours; five divisions, 30 days (see Figure D–2).

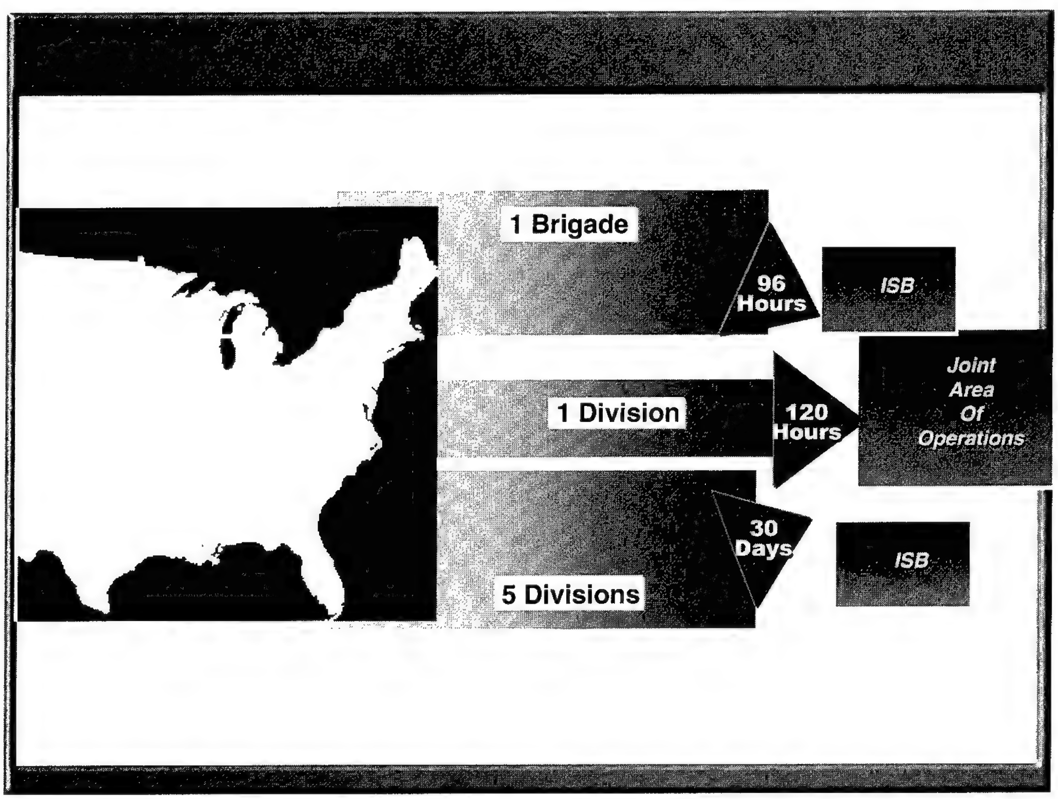


FIGURE D–2. OBJECTIVE FORCE DEPLOYMENT TIMELINES

- The critical components (move, shoot, communicate) of combat equipment will not fail during employment (combat).
- The warfighter will be unencumbered from combat downtimes associated with combat equipment's demand for logistics support.
- The number and types of logistics people, supplies, and equipment currently required to be deployed from CONUS to the area of operations will be reduced.
- The family of Future Combat Systems (FCS) and other new combat systems have significantly reduced life-cycle costs (LCCs).

Combat system designs dictate the OPTEMPO of logistics support and and LCCs. The more often systems break, corrode, short-circuit, overheat, or run out of fuel or batteries, the more LCCs are increased. The development, design, and procurement of future combat systems with significantly reduced logistics support will leave a future legacy of more reliable and sustainable combat systems.

Scientific research areas such as nanoscience and biomimetics have the potential to enable revolutionary system designs. The following examples of the technology areas that can design out the demand for logistics. These examples are focused on the FCS.

Logistics demand reduction for the Objective Force requires S&T investments in the following areas:

- **Energy Sources.** The production, storage, and distribution of energy on the battlefield are the most demanding logistics functions. Current resupply of fuels and batteries becomes increasingly difficult with the addition of more sophisticated electronic equipment and the requirements for greater speed and ranges for combat equipment. New propulsion systems driven by new energetic fuels are also required. Reducing consumption by 75 percent will require R&D of alternatives to fossil fuel as opposed to efficiencies to be gained through continued marginal increases in economies of scale with current fuels.

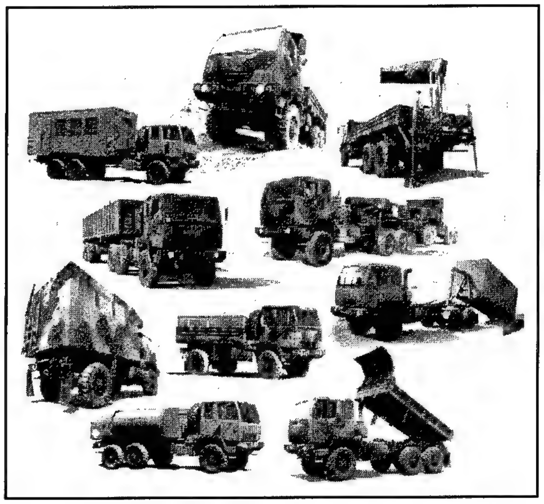
- **Intelligent Systems.** Typically referred to as "predictive logistics," future intelligent combat systems will predict and report weapon system component and subsystem failures, monitor consumables (ammunition, fuel, etc.), and predict and report resupply requirements based on actual real-time usage. Onboard real-time prognostics and reporting and self-healing systems can be realized through the exploitation of advanced technologies. In addition to weapon system prognostics, intelligent systems can be combined with advanced materials and thermodynamics to control environmental conditions within shipping containers.

- **Command and Control/Decision Support Tools.** In the future, the logistician will be seamlessly integrated into the warfighters' planning, as opposed to the current traditional human interfacing that occurs during planning of combat operations. This requires information fusion—the timely and accurate access and integration of logistics data across units and combat support agencies throughout the world, providing reliable asset visibility and access to logistics resources in support of the warfighter.

- **Advanced Materials**. Advanced materials that reduce the weight or volume of equipment and vehicles will substantially reduce the logistics burden. This will result not only in a reduced demand for fuel, but also will significantly relieve the logistics deployment demand. Advanced materials that are molecularly perfect will fail less often. This increased reliability of combat systems reduces the logistics demand for maintenance.

- **Design.** Metal surfaces that come together at right angles tend to draw and collect water vapors. Moisture continuously forming on the same surface eventually leads to corrosion of that surface. This corrosion problem can be overcome by curving the surface at adjoining metal surfaces.

The complex and labor-intensive scenes frequently encountered at ports of debarkation during recent deployments could be eliminated in the future because there will be limited need for spare parts, test maintenance and diagnostics equipment, batteries, and other combat readiness support. The Army seeks to "fight off the ramp" (Figure D–3) on urban terrain for up to 72 hours without resupply. Forces that can be projected directly into combat without the near-term requirement for immediate logistics intervention to maintain their combat readiness are compatible with the early entry concept of "fighting off the ramp" being advocated by the Army.



Reduce or eliminate the requirement for these vehicles on the future battlefield

"Fight off the ramp"

FIGURE D–3. FIGHTING OFF THE RAMP

Today the individual dismounted soldier requires a resupply of batteries up to four times per day. In a combat environment, logisticians transit the battlefield multiple times per day to sustain OPTEMPO. The Army needs to develop high-density portable energy sources to replace current batteries.

The mobility, deployability, and sustainability essential to the Army's Objective Force concepts cannot be achieved without dramatic changes in how the force is projected and sustained. Through CS/CSS Transformation, the Army will evolve into a global, distribution-based logistics system that substitutes logistics velocity for logistics mass, taking maximum advantage of technological breakthroughs. Technology will be leveraged to fuse new organizational constructs, concepts, transportation, information, and logistics systems, fundamentally reshaping the way forces are projected and sustained. The CS/CSS Transformation requires logistics to obtain a number of capabilities that the Army currently does not have. Underlying the future distribution-based system, a wide array of advanced technologies must be researched, developed, applied, and acquired, including real-time situational understanding, anticipatory and precision logistics, seamless logistics system, and streamlined acquisition. Investment in these technologies will reduce logistics operational encumbrances that directly impede our capability to support the warfighters' prosecution of the battle.

TECHNOLOGY AREAS

ESSENTIAL TECHNOLOGY AREAS FOR LOGISTICS	
Sensors	Smart/brilliant munitions
Diagnostics/prognostics	Artificial intelligence
Source data automation	Satellite communications
Sentinel systems	Advanced manufacturing
Intelligent networks	Space operations
Natural language processors	Biometrics
Voice-activated automation	Nanotechnology
Advanced materials	Microminiaturization
Robotics	Fuels

Warfighters are demanding technologies for their combat equipment that will allow movement about the battlefields of the future with near impunity—day, night, all-weather, and all-terrain, against virtually any threat. For the logistician to be capable of sustaining and maintaining this combat force, there must be similar battlefield mobility and situational awareness built into logistics equipment and command and control systems. A glimpse of the future tells us that logisticians must have mobility and agility on the battlefield equal to that of the warfighter. Technologies must provide predictive capability to logisticians, thus relieving their reactive burden imposed by today's weapon systems. Advanced warfighting technologies provide significant added value to logistics functions.

TECHNOLOGY DEMONSTRATIONS

Technology Demonstrations linked to DoD and Army visions are depicted in Table D–1.

TABLE D–1. LOGISTICS PAYOFFS FOR RAPID DEPLOYMENT AND REDUCED SUSTAINMENT

Initiative	Vision Supported				Benefit of Initiative
	Joint Vision 2010	Army Vision	CS/CSS Transformation	DoD SROs	
EARLY ENTRY & RESUPPLY					
Affordable Precision Airdrop Resupply TD	●	●	●	●	Demonstrate semirigid deployable wing technology to assist in precision, high-offset delivery of supplies and equipment. Provides precision early-entry supply capability in high-threat insertion that does not currently exist.
Precision Roll-On/Roll-Off Air Delivery (III.LG.2000.03)	●	●	●	○	Demonstrates/integrates technologies for air delivery of cargo; provides 60% reduction in rigging time Significantly reduces current intermodal time delays.
Modular Unmanned Logistics Express TD	●	●	●	●	Demonstrates a UAV configuration that supports automated logistics movement of modular payloads up to 10,000 lb; the aircraft will be VTOL, self-deployable, & capable of all-weather operation. Provides a future precision capability to supply/resupply combat forces.
Enhanced Coastal Trafficability & Sea State Mitigation ATD (III.LG.1998.02)	●	●	●		Provides initial early entry of large quantities of supplies where seaports are otherwise inaccessible due to high sea states. Reduces engineering equipment needed to conduct logistics operations over the shore.
Robotic Follower ATD (III.GC.2000.04)	●	●	●	○	Develops leap-ahead technology with significant logistics implications. Demonstrates advanced robotic capabilities on a set of combat and combat service support vehicle concepts.

TABLE D–1. LOGISTICS PAYOFFS FOR RAPID DEPLOYMENT AND REDUCED SUSTAINMENT (CONT'D)

Initiative	Vision Supported: Joint Vision 2010	Army Vision	CS/CSS Transformation	DoD SROs	Benefit of Initiative
LOGISTICS DEMAND REDUCTION—RESUPPLY					
Objective Force Logistics Technology TD	●	●	●		Develops & demonstrates advanced ammunition logistics technologies to reduce the logistics burden, enhance strategic mobility, & provide responsive support.
Multirole Armament & Ammunition ATD (III.WP.1999.01)	●	●	●	●	Provides rapid, autonomous rearm & resupply for FCS; capability of achieving reduced logistic system visions of an FCS; up to 67% reduction in rearm time & manpower; 50% reduction in ammunition volume compared to the Abrams tank. Enables rapid, integrated, anticipatory rearm & resupply for FCS.
Electromagnetic Gun Technology (IV.WP.2001.01)	●	●	●		EM armaments would greatly reduce the sustained requirements of conventional cannon systems.
Advanced Light Armaments for Combat Vehicles (III.WP.2000.03)	●	●	●		Advanced primary & secondary armaments for FCS; improved logistics & increase stowed kills for smaller/lighter objective forces.
120-mm Extended-Range Mortar Cartridge (IV.WP.1998.05)	●	●	●		Reduced logistics burden via reduced number of rounds per kill, 50% greater range provides increased flexibility (greater array of targets with single munition).
Area Denial Systems (III.EN.1998.01)	●	●	●		25% load has same effectiveness as current barrier systems. Significantly reduces the quantity of munitions that need to be supplied.
Metal Matrix Composites for Ordnance Applications (IV.MA.2001.01)	●	●	●		Adapts continuous fiber MMC technology from commercial sector to enable a 50% weight reduction of future projectiles/armaments.
Collinear Explosively Formed Penetrator Warhead TD		●	●		Paves the way for smaller/lighter platforms that retain large-caliber performance characteristics.
Multiple EEP Warhead for APS TD		●	●		Greatly reduces platform weight (armor) requirements & therefore directly impacts fuel consumption, operating range capability, & fuel resupply requirements.
Compact Shaped-Charge Warhead TD		●	●		State-of-the-art design coupled with unique initiation techniques & materials will produce warheads that are 50%"shorter" yet equally effective when compared to current conventional designs; logistics can package & ship approximately twice the ammunition in the same volume.
Combined Effects Shaped-Charge Warhead TD		●	●		Greater lethality without increased weight of volume to be shipped & delivered by logistics support.
Military Operations on Urbanized Terrain ACTD (III.SH.1997.01)	●	●	●		Open system architecture facilitates a large reduction in future integrated logistics support LCCs; realistic scenarios need to include MOUT resupply & other logistics functions.
Agile Commander ATD (III.C4.2000.01)		●	●		Provides 30–50% reduction in the number of vehicles & equipment associated with the TOC to be sustained & maintained.
Water Purification Technology (IV.LG.2000.04)	●	●	●		Reduces logistics need by 25%; provides individual & small-unit water on site.
E-Sustainment TD	●	●	●		Demonstrates wholesale & retail logistics integration.
Rapid Analysis of Food & Water for Chemical & Microbial Contaminants (IV.ME.1999.01)		●	●		Reduces logistics demand and host nation support.
Rotorcraft Open Systems Avionics (IV.AV.2000.02)	●	●	●	●	Defines open systems architecture to reduce costs of maintaining avionics systems; 50% decrease in unique module; 70% increase in plug-and-play.
Wide-Span Airbeam Shelters for Logistics Applications (III.LG.1999.02)		●	●		Improves maintenance capability in austere environment.
Combat Rations for Enhanced Warfighter Logistics (III.LG.2000.02)			●		Provides fresh-like tailored rations with 20% reduction in weight & volume & 30% reduction in ration field waste, which will reduce the logistics footprint.

TABLE D–1. LOGISTICS PAYOFFS FOR RAPID DEPLOYMENT AND REDUCED SUSTAINMENT (CONT'D)

Initiative	Vision Supported: Joint Vision 2010	Vision Supported: Army Vision	Vision Supported: CS/CSS Transformation	Vision Supported: DoD SROs	Benefit of Initiative
LOGISTICS COMMAND & CONTROL—SITUATIONAL UNDERSTANDING					
Logistics Command & Control ATD (III.LG.1999.01)	●	●	●		Revolutionizes tactical decision making process for Army logisticians; attains real-time planning & situation data visualization.
Dynamic Readdressing & Management for Army 2010 (IV.C4.2000.01)	●	●	●		Demonstrates network healing; automated network management.
Training Tools for Web-Based Collaborative Environments (IV.SP.2001.01)	●	●	●		Supports anytime/anywhere training paradigm.
On-the-Move Tactical Satellite Communications Technology (III.C4.1999.01)	●	●	●	●	Provides capability to communicate logistics-essential data on the move.
Battlespace Tactical Navigation (III.C4.1999.02)		●	●		Enhances accuracy of location & tracking of all logistics assets.
Multifunctional On-the-Move Secure Adaptive Integrated Communications (MOSAIC) ATD (III.C4.2000.02)	●	●	●	●	Allows information to flow—wherever it exists, in any form, to wherever it is needed in any form.
Collaboration Technology for the Warfighter (IV.C4.1999.01)	●	●	●		Contributes to logistics situational awareness, battlefield distribution, velocity management, & interactive electronic technical manuals.
Rapid Terrain Visualization ACTD (III.EN.1996.01)	●	●	●	●	Provides battlefield situational awareness required to plan & execute logistics missions.
Advanced Combat Identification Architecture (III.C4.1999.03)	●	●	●	●	Provides situational awareness to prevent fratricide—resupply, maintenance missions.
Battlefield Ordnance Awareness (III.SS.1997.01)	●	●	●		Provides near-real-time ordnance reporting system using onboard processing with space sensors; provides capability to identify by ordnance type blue force ordnance inventory requirements.
Advanced Battlefield Processing Technology (IV.C4.1998.01)	●	●	●		Enhances C^2 decisionmaking.
Cognitive Engineering of the Digital Battlefield (IV.SP.1998.01)	●		●		Provides predictive models & performance metrics for assessing TOC design; functional roadmap for guiding staff officer training.
Fourth-Generation Crew Station TD	●		●	●	Provides advanced 3D display technology transferable to telemaintenance.
LOGISTICS DEMAND REDUCTION—SYSTEM RELIABILITY					
Concepts for 21st Century Truck-Based Tactical Vehicles (IV.GC.2000.01)	●		●	●	Enables virtual prototyping design explorations of vehicles.
Future Combat Systems (III.GC.2000.03)	●	●	●	●	Reduces up to 90% of logistics/sustainment demands.
Real-Time Collaborative Engineering TD	●	●	●		Provides the ability to apply advanced visualization capabilities to make informed development, evaluation, integration, & tradeoff decisions.
Rotorcraft Drive Systems for the 21st Century (III.AV.2001.01)		●	●	●	Provides major advances in power transmission technology and lubricants, and significantly improved readiness & O&S cost reduction.
More Electric Rotorcraft TD		●	●	●	Provides advanced electromechanical/electrical power generating devices to replace hydraulic/mechanical drive systems (fly by wire).
Variable-Geometry Advanced Rotor Technology (IV.AV.1999.01)	●	●	●	●	Increases range 91% or payload 66%; increases reliability 20%; reduces O&S costs 21%.
Rotary-Wing Structures Technology (III.AV.1997.01)		●	●	●	Increases reliability 20% and maintainability 10%; reduces O&S costs 5% for utility type rotorcraft.

TABLE D–1. LOGISTICS PAYOFFS FOR RAPID DEPLOYMENT AND REDUCED SUSTAINMENT (CONT'D)

Initiative	Vision Supported: Joint Vision 2010	Army Vision	CS/CSS Transformation	DoD SROs	Benefit of Initiative
LOGISTICS DEMAND REDUCTION—SYSTEM RELIABILITY (CONT'D)					
Advanced Rotorcraft Aeromechanics Technologies (IV.AV.1997.01)		●	●	●	Increases MTBF; increases reliability & maintainability; reduces O&S costs.
Low-Cost Active Rotor (IV.AV.2000.03)		●	●		Provides 40% reduction in rotorcraft vibration—a major factor in engine component failure.
Cannon Wear & Erosion (IV.MA.1998.01)		●	●		Improves gun barrel life tenfold compared to current equivalent gun barrels.
Helicopter Active Control Technology (III.AV.1996.01)		●	●		Enables advanced fault-tolerant systems to maintain reliability & simplify maintenance.
Aircraft System Self-Healing TD	●	●	●	●	Compensates for premature subsystem or component failure; changes repair concept.
LOGISTICS DEMAND REDUCTION—PROGNOSTICS					
Rotary-Wing Vehicle Prognostics TD		●	●	●	Predicts remaining component & system safe life; reduces maintenance labor hours & substantially increases aircraft availability for service.
Petroleum, Oil, & Lubricants Quality Analyzer & Sensors (IV.LG.2000.03)		●	●	●	Develops & demonstrates device(s) to diagnose mechanical problems & extend oil & lubricant life.
Remote Readiness Asset Prognostics/ Diagnostics System (IV.LG.2000.05)	●	●	●	●	Provides near-real-time status of combat equipment. Enables anticipatory resupply, munitions prognostics/diagnostics, antitamper protection, & improved readiness. Develops & demonstrates a small, low-cost, microchip-based device to provide near real time.
Survivable, Affordable, Repairable Airframe Program TD	●	●	●	●	Provides new efficient & affordable diagnostics & repair concepts—30% reduced repair times.
LOGISTICS DEMAND REDUCTION—POWER & ENERGY					
Advanced Tactical Fuels & Lubricants (IV.LG.2000.02)	●	●	●		Provides for improved POL that will reduce fuel consumption, reduce maintenance demands, & improve durability of components; reduces maintenance costs by 25% & increases fuel economy by 4%.
Combat Vehicle Concepts & Analysis (IV.GC.1998.01)		●	●		By FY02, develops vehicle concepts for the Army's next generation of combat & combat support vehicles; provides 33% reduction in vehicle weight.
Integrated Power Generation & Management Technologies (IV.LG.2000.01)	●	●	●	●	Optimizes battery capacitor hybrid size, weight, & cost; demonstrates optimized electrochemical technology on a 5-kW testbed; evolves a tool for system-level, low-power design; delivers hybrid & kinetic prototypes for field trials; demonstrates power OTM; demonstrates reduced power consumption.
Power Conversion Technology for FCS (IV.LG.2001.01)	●	●	●		It is an enabling technology for hybrid/electric drive capability that greatly improves fuel efficiency & thereby reduces the logistics footprint of the Objective Force; reduces converter size by 60–75% & weight by 50%.
Reforming Diesel (Cogeneration) (III.LG.1998.01)	●	●	●	●	Reduces dependency on field generators: reduces weight, cube, cost, & signature.
Integrated High-Performance Turbine Engine Technology Joint Turbine (III.AV.1998.04)	●	●	●	●	Provides 25% reduction in fuel consumption & 60% increase in power-to-weight ratio.
Future Scout & Cavalry System ATD (III.GC.1997.01)		●	●		Provides advanced lightweight materials & electric drive to be supplied & maintained.
Future Combat System Integrated TD	●	●	●	●	Provides leap-ahead capabilities within combat vehicle; reduces vehicle weight up to 70%.
Combat Hybrid Power Systems (IV.GC.1999.01)	●	●	●	●	Provides hybrid electric power systems that result in greatly improved fuel economy.
Ground Propulsion & Mobility (III.GC.1996.01)	●	●	●		Provides critical engine electronic drive, track & suspension, & storage devices.

TABLE D–1. LOGISTICS PAYOFFS FOR RAPID DEPLOYMENT AND REDUCED SUSTAINMENT (CONT'D)

Initiative	Vision Supported: Joint Vision 2010	Army Vision	CS/CSS Transformation	DoD SROs	Benefit of Initiative
LOGISTICS DEMAND REDUCTION—POWER & ENERGY (CONT'D)					
Ballistic Protection for Future Combat Systems (IV.GC.2000.02)		●	●		Provides lighter combat vehicles in the future.
Alternative Propulsion Sources TD	●	●	●	●	Explores advanced propulsion concepts for manned & unmanned air vehicles.
High-Energy, Cost-Effective Primary & Rechargeable Batteries (IV.LG.1997.01)	●	●	●	●	Provides a battery with energy content 20% greater than that of the existing nickel-metal hydride battery.
Conducting Nanocomposites & Nanofibers for Warrior Systems (IV.SP.2000.01)	●	●	●	●	Develops & produces leap-ahead technology that provides Land Warrior lightweight power generating devices from new conducting polymers.
Lightweight Soldier (IV.SP.1999.01)		●	●		Reduces power requirements and logistics demand.
Low-Power Display Components (IV.SN.1999.03)		●	●	●	Reduces the number of batteries that must be maintained for each unit. Reduces power consumption by more than 50%.

● Provides significant capability ○ Provides some capability

DOD STRATEGIC RESEARCH AREAS

The DoD S&T community has identified six SRAs where the long-term potential exists for developing advanced technologies to meet requirements: nanotechnology, smart structures, intelligent systems, biomimetics, broadband communications, and compact power sources. These six DoD SRAs have been adopted in the Army S&T program. Table D–2 portrays the value added for logistics from the application of the technologies represented in the six DoD SRAs.

TABLE D–2. LOGISTICS APPLICATIONS OF DOD SRA TECHNOLOGIES

Nanotechnology	Smart Structures	Intelligent Systems	Biomimetics	Broadband Communications	Compact Power Sources
Changes concept of manufacturing—do anywhere	Vibration damping & reduction via embedded sensors	Execution of logistics system tasks without human intervention except when desired	Medical applications to include immediate repair of broken/crushed bones & combat injuries	Provide field users with flexible, mobile, & easily deployable communications conduits	Reduce fuel & power storage & distribution requirements significantly
Synthesis from local materials	Reduced maintenance requirements	UGV/UAV; application of intelligent systems will decrease force structure & improve system response time	Repairs to combat damaged equipment	Untether logistics processes from fixed wire sites	Increased operational capability of the soldier as a system
Sophisticated, extremely lightweight material	Reduced resupply & transportation requirements	Robots to handle materiel that is dangerous, heavy, or sensitive	Designer vaccines & drugs for quick return to healthy status	Increased data pass capability	Handle power requirement of dismounted soldier: heating & cooling, computer use, communications transmissions

TABLE D–2. LOGISTICS APPLICATIONS OF DOD SRA TECHNOLOGIES (CONT'D)

Nanotechnology	Smart Structures	Intelligent Systems	Biomimetics	Broadband Communications	Compact Power Sources
Quantum computing at very high speed	Improved storage with ambient temperature control	Decision support system "brains" to monitor individual weapon systems & prevent failure	Lightweight structures & system components with ultrareliability that are virtually frictionless	Reduce frequency of data reporting	Reduce dependence on fossil fuels
Prophylactics & cures for chemical/biological agents	Secure system containers for critical resources	Reduced logistics distribution requirements by accurately assessing potential component failures & using collective knowledge of entire weapon system	Impact-resistant material that can be grown in combat area	Integrate weapon system sensors reporting prognostic information on a broad scale	Reduce resupply requirement for power sources
Ultra-strong fibers	Reduced damage to material by adjusting containers & structures for various shock & impact conditions	Improved logistics planning via multisensory perception development	Lightweight armor—reduced logistics footprint across the board	Evaluate the "health" of entire groups of common weapon systems individually & independently	Reduce environmental issues associated with battery disposal
Programmed ultra-reliability	Structures respond to external stimuli & adapt accordingly	Improved exoskeletons to reduce force structure for materials handling equipment—increased lift capability	High-resolution sensors to detect imperfections & to provide enhanced capability to troubleshoot faults	Improve timeliness of the logistics communications support structure	Required to develop containers with micro heat pumps & long-term power capability for independent operations
Reduced logistics demand	Retain history of access and denials/automatic inventory	Reduced hazardous exposure during critical item operations or repair	Development of superconductor material could lead to propulsion without motors or gears as we know them		
Environmentally enhancing	Reduce logistics requirements for CBD Immediate battle damage assessment & failure reporting Improve fuel storage capability Biomedical applications including in vivo sensing & control Rapid nondestructive testing responses (less out-of-service time)		Noncorrosive & nonerosive		

Nanotechnology

Achieve dramatic, innovative enhancements in the properties and performance of structures, materials, and devices on the nanometer scale (i.e., tens of angstroms). Fabrication of structures at the nanometer scale will enable manufacturing of more reliable, lower cost, higher performance, and more flexible electronic, magnetic, optical, and mechanical devices. The potential exists for "battlefield manufacture" of materials required to prosecute a conflict.

Smart Structures

Demonstrate advanced capabilities for modeling, predicting, controlling, and optimizing the dynamic response of complex, multielement, deformable structures used in land, sea, and air vehicles and systems. Smart structures offer significant potential for expanding the effective operations envelope and improving critical operational characteristics for weapon systems. Logistics applications include a "self-healing" area for structural damage detection and mitigation systems.

Intelligent Systems

Enable the deployment of advanced systems able to sense, analyze, learn, adapt, and function effectively in changing or hostile environments. Intelligent systems typically consist of a dynamic network of agents interconnected via spatial and communications links that operate in uncertain and dynamically changing environments using decentralized or distributed input and under localized goals that may change over time. Intelligent systems must be capable of gathering relevant information about their environment, analyzing its significance in terms of assigned functions, and defining the most appropriate course of action consistent with programmed decision logic. Built-in, real-time, self-reporting prognostics for weapon systems is an application of this technology that will dramatically reduce logistic burdens, reduce associated costs, and significantly improve the mean time to repair.

Biomimetics

Enable the development of novel synthetic materials, processes, and sensors through advanced understanding and exploitation of design principles found in nature. Materials and structures of intricate complexity that exhibit remarkable properties are found throughout the biological world. Many of these biological systems derive their functionality from fabrication through several levels of self-assembly involving molecular clusters organized into structures of different length scales. The result is an optimized architecture tailored for specific applications through molecular, nanoscale, microscale, and macroscale levels that is unobtainable through conventional equilibrium-based synthetic fabrication methods. The superior strengths and other properties such as noncorrosiveness and light weight of biomimetic materials lend themselves to solving and reducing numerous logistics burdens.

Broadband Communications

Provide fundamental advances enabling the rapid and secure transmission of large quantities of multimedia information (speech, data, graphics, and video) from point-to-point, broadcast, and multicast over distributed networks for heterogeneous C^3I systems. Research is needed to significantly improve the throughput, survivability, and security of communication networks critical to logistics viability and to the success of future military operations.

Compact Power Sources

Achieve significant improvements in the performance (power and energy density, operating temperature, reliability, and safety) of compact power sources through fundamental advances relevant to current technologies (e.g., batteries, fuel cells) and the identification and exploitation of new concepts. Efficient, long-life, durable, and quiet compact power sources are a critical requirement for electronics, communications, heating and cooling, weapons, and propulsion systems.

ARMY STRATEGIC RESEARCH OBJECTIVES

In addition to the DoD SRAs, the Army has identified three SROs of its own; these Army-specific SROs are summarized below. Table D–3 depicts potential logistics benefits from exploitation of the technologies being researched and developed in these Army SROs.

TABLE D–3. LOGISTICS APPLICATIONS OF NEW ARMY SRO TECHNOLOGIES

Enhancing Soldier Performance	Microminiature Multifunctional Sensors	Armor Materials by Design
Changes concept of "feeding" soldiers; nutritional feeding of the future will reduce logistics burden Understanding of soldier thought process and endurance along with focused training could result in less damage to combat equipment due to fatigue, stress, or ineffective training	Onboard, real-time, self-reporting weapon system prognostics. Results in real-time situational understanding of actual combat status of forces Telemaintenance Telemedicine	Reduced armor weight. Results in reduced logistics demand for fuel Reduced battlefield vulnerability of logistics assets leading to increased survivability of logistics assets

Enhancing Soldier Performance

Achieve the objective force objectives of knowledge and speed. Research is focused on ways to maximize soldiers' mental and physical performance, enhance their endurance, increase their ability to make decisions, mitigate stressful effects on them, and improve leadership training. Efficient, mentally agile, physically capable of performing under stress are critical requirements for modern warfare of the 21st century.

Microminiature Multifunctional Sensors

Achieve the objective force requirements for real-time situational awareness. These sensors have a multitude of functional capabilities including, but not limited to, chemical and biological detection, inertial navigation, visual sensing, and system health and environmental monitoring. Other aspects of this research seek to reduce the power requirements for communicating sensor results to a control center. This research will also enable CSS personnel to make decisions based on better information about the locations and status of available supplies and equipment.

Armor Materials by Design

Achieve the objective force requirements for fielding lighter and more deployable heavy forces and making light forces more survivable. Also, personal armor is too heavy and does not adequately protect the individual against a broad spectrum of threats. Research is basically focused on technologies for design, processing system integration, and manufacturing to meet performance requirements for mobility and survivability.

ANNEX

E GLOBAL SCIENCE AND TECHNOLOGY WATCH

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E GLOBAL SCIENCE AND TECHNOLOGY WATCH

This annex plays a supporting role to the Army's capstone science and technology planning document by providing:

- A snapshot assessment of global technology developments.
- An index of international organizations and related resources by technology category.
- A tool for exploiting the explosion of international S&T programs by acting as an information resource in technologies of interest to the Army.

Given the widespread and increasing proliferation of militarily relevant technologies, it is important that the Army's approach to international collaboration is both focused and productive.

A STRATEGIC OVERVIEW

The globalization of science and technology is an irreversible process that is radically changing the environment in which the Army trains, operates, and develops new systems and strategies. This globalization of S&T affects the Army's ability to pursue enabling technologies in support of Future Combat Systems (FCS) for the Objective Force. The Army's International Technology Leveraging strategy (described in Volume I), which has become an increasingly important facet of technology development strategies, given limited resources and new international threats and partners.

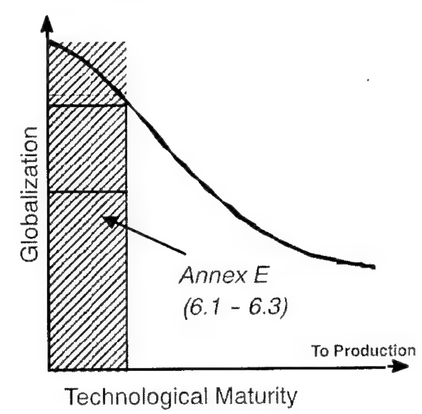

FIGURE E–1. FOCUS OF TECHNOLOGICAL COVERAGE

Globalization has also been viewed as a vulnerability for the United States, in that it can accelerate technology development for potential adversaries and increase U.S. dependence on international technology sources (Figure E–1). By increasing U.S. influence with foreign nations and providing access to technological strengths residing outside the United States, however, globalization also provides many new possibilities to enhance U.S. policy options and defense capabilities. This annex provides a tool for exploiting the phenomenon by acting as an information resource to access international areas of expertise in technologies of interest to the Army. The need for this kind of "technology watch" of global capabilities has been supported at all levels of the Department of Defense, including both the Office of the Deputy Under Secretary of Defense for Science and Technology and the Defense Science Board.

1 Vision

International military–industrial–academic partnerships contribute to the warfighting capabilities of our soldiers and our allies by maintaining truly world-class technology and industrial bases built on a global-minded workforce and the best available industrial capabilities and services. As shown in Figure E–2, our International Armaments Cooperative Strategy (IACS) is a comprehensive effort to focus our diverse goals to:

- Maintain a global awareness of the best technological developments, and develop appropriate leveraging strategies.
- Arrange data and personnel exchanges, and participate in selected international forums to optimize the benefit to the U.S. Army.
- Develop senior-level guidance based on well-thought-out leveraging strategies.

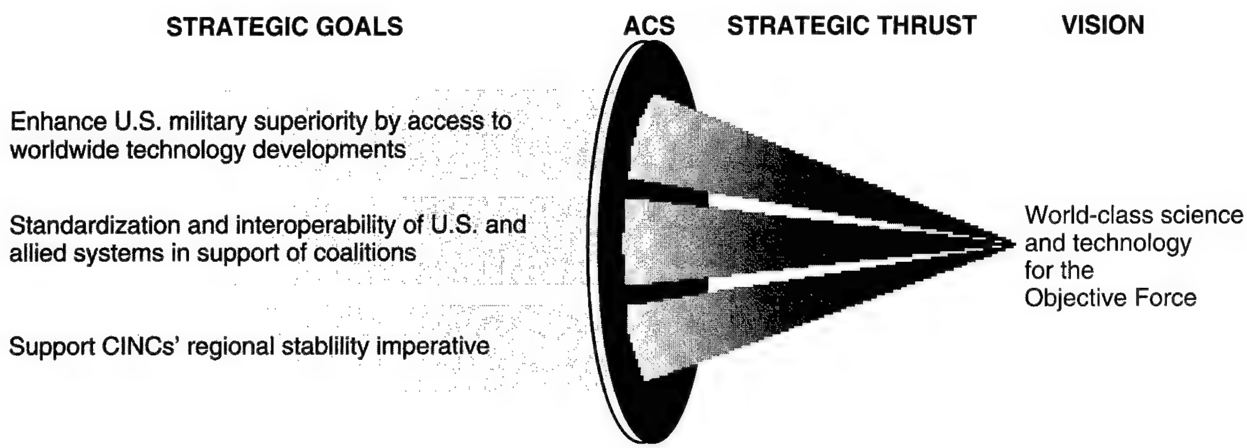

FIGURE E–2. THE INTERNATIONAL ARMAMENTS COOPERATIVE STRATEGY FOCUS

2 Role of Annex in International Programs

Effective international cooperation demands both the development of sound, long-term partnerships and the ability to respond opportunistically when the occasion arises. This annex is designed to accomplish both these objectives. First, this annex provides insights into the broad capabilities of other countries that can be used to allocate resources to develop and cultivate cooperative programs with partners that are most likely to provide reliable long-term benefits. At the same time, identification of specific niches of excellence in research and application provides a basis for responding quickly to the changing political–military landscape while managing potential benefit to the Army science and technology community. The annex also supports the development of international technology cooperation programs that promote interoperability among coalition partners and support peacetime engagement among allies.

As discussed in Annex F, identification of an opportunity for partnering in this annex establishes the existence of an acceptable technological quid pro quo. Within the guidelines of identified technologies and countries, this annex provides an authoritative basis for the initiation of international agreements, as shown in Figure E–3. However, the proponent organization must make the final determination that the specific quid pro quo exists for concluding cooperative agreements. This annex offers an annually updated snapshot in time, and new and rapidly

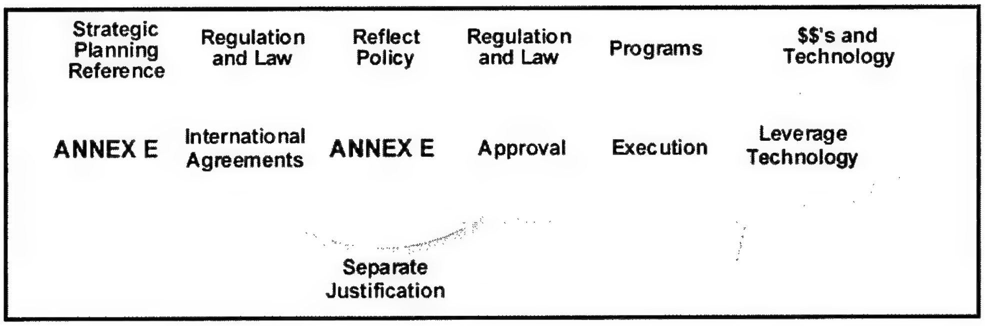

FIGURE E–3. ROLE OF ANNEX E IN INTERNATIONAL PROGRAMS

emerging S&T development may not be reflected. Because this document is publicly released, sensitive or classified information is not included.

The ASTMP is the Army's capstone S&T strategy planning document. This annex plays a supporting role in several of the Army plan's mission areas. As a planning and reference tool, this annex provides senior Army management with a roadmap for initiating discussions with partnering countries on technology cooperation.

3 Country Capabilities and Trends Analysis

Understanding trends is key to an effective strategy. Science and technology is advancing rapidly, and some opportunities may be time sensitive. This analysis of technology and research capabilities spans the entire globe. In all areas, both commercial and government capabilities and programs are assessed. More than in previous years, multinational programs are identified as targets for U.S. cooperation in the various disciplines.

The criteria for determining country capabilities and associated trends were the following:

- *Comparative demonstrated technical performance*—countries were examined for materials, components, or systems produced indigenously, relative to best U.S. practice.
- *Indicators of recognized quality*—the market share of commercial and defense products based on the research and technology areas in each nation was considered as part of the capability assessment.
- *Strength and balance of supporting infrastructure*—the number of R&D organizations, diversity of participation (industry, academia, and government), and level of investment were considered.
- *Expert consensus*—U.S. Army subject matter experts reviewed the analyses.

Technology and research areas addressed are described in detail in Chapters IV and V. These areas span Army interests from research to advanced development (Figure E–1). They have been identified as enabling the Army to upgrade currently fielded systems and to investigate new high-risk areas having significant potential enabling capabilities need for the Objective Force.

4 Global Technology and Research Capability Overview

Leadership in applied technology with identified military relevance is shared among relatively few countries—the United States and its NATO allies France, Germany, and the United Kingdom, and major non-NATO ally Japan. Other countries identified as having significant capabilities include Israel, Canada, China, Russia, Italy, Sweden, Australia, and the Netherlands. In a number of countries, the trend is toward the development of more advanced capabilities. In most areas, capability is widely disseminated, with three or more countries sharing world lead-

ership. Even in those areas where the United States holds a unilateral lead, other countries provide significant technology leveraging opportunities in specific areas.

The number and geographic distribution of countries having significant S&T capabilities is large and can be expected to increase. In the global economy, reliable sources of electronics, computers, sensors, and new materials are becoming more widely available as advances spread rapidly throughout global markets. Computers and electronics are simply commodities—basic tools for studying the scientific areas that these countries have chosen, such as life sciences, biology, chemistry, and behavioral and medical sciences.

Figure E–4 provides a rank ordering of country capabilities based on the total number of high-quality leveraging opportunities that are identified in this annex. The capabilities highlighted correlate to the areas where countries are shown in the individual subsection tables as having world-class capabilities and a level of activity that is expected to enhance or at least maintain their relative position.

LEVERAGING OPPORTUNITIES	BASIC RESEARCH	APPLIED RESEARCH
IN A MAJORITY OF ARMY S&T AREAS	Germany France UK Japan Russia	France UK Germany Japan
IN MANY ARMY S&T AREAS	Israel Canada China Sweden Netherlands	Israel Russia Canada Sweden Netherlands Italy
IN ONE OR MORE ARMY S&T AREAS	Australia Switzerland Italy Korea India Finland Poland Taiwan South Africa Austria Denmark Indonesia Brazil Czech Republic Spain Slovakia Singapore Belgium Cuba Hungary Turkey Argentina	Switzerland Korea China Australia Austria Singapore Poland India New Zealand South Africa Denmark Brazil Czech Republic Thailand Belgium Malaysia Kenya Norway

This rank ordering is based on the number of world-class leveraging opportunities across all research and technology areas of interest to the Army, as identified in Annex E, Volume II.

FIGURE E–4. RANK ORDERING OF COUNTRY CAPABILITIES

5 The Future

Although scientific and technological capabilities are important determiners of future capabilities, global economic forces will also play an important role. These forces will inevitably change the distribution of wealth, and with that shift, the future potential for technological and scientific leadership. The position of the United States as the largest economy and market in the world is changing. There is an evolution towards at least three major economies and markets—Europe, Asia–Pacific, and North America. As each market develops, other countries will emerge with increasing economic and technological strength. Accordingly, U.S. Army R&D elements based in these nations are being asked to assume a larger role in the building of this annex. The FY01 document was enhanced through the participation of the Army Research, Development, and Standardization Group–Canada. Cooperation of this type will expand in the future.

Also of increased importance is the role of industry to the Army. DoD has indicated that there will be a renewed emphasis on the developments being made in the private sector, both foreign and domestic. It appears likely that the focus of Army basic and applied R&D will be toward increasing cooperation with the private sector.

For the near term, the United States and our traditional allies will probably maintain a commanding dominance in the physical sciences and in electronics and computer hardware. This will perpetuate a worldwide abundance of devices, systems, and instruments, including sophisticated weapons. In other areas, however, an increasing number of countries will have world-class capabilities. In areas that do not require a large infrastructure, investment, or a well-educated population, many countries will contribute effectively to the global market. Software, for instance, is an area in which good mathematical skills and education are the primary ingredients, especially because powerful computers are becoming widely available. The life sciences, biology, chemistry, medicine, and behavioral science are other areas in which many countries have the requisite skills to compete effectively.

This annex provides the basis for building a strategic approach to international S&T cooperation. With the growing emphasis on coalition warfare, as seen in the past year, it is important not only to leverage global technology, but to keep the channels of communication open and viable. Given the widespread and increasing number of opportunities for technology leveraging—along with decreasing resources—it is important that the Army's approach to cooperation be both focused and productive.

6 Annex E Overview

Sections B and C provide brief overviews of the international opportunities in technology development and basic research, respectively. The technological capabilities identified have the potential to contribute to the objectives and milestones identified in each area addressed in Volume I, Chapters IV[1] and V. Within each S&T area, opportunities to address specific needs are also identified. Each specific opportunity includes a brief description and justification highlighting potential benefits of leveraging the international capability. Examples of foreign facilities and multinational programs with world-class efforts in areas of interest to the Army are also identified. Army Material Command (AMC) points of contact (POCs) and AMC major subordinate commands' international POCs (IPOCs) or project officers for each of the technologies and agreements are cited within the appropriate sections. More complete contact information for

[1]The technology areas in this annex do not precisely match those of Chapter IV.

U.S. POCs is provided on the last page of this annex.

A summary, or trend, chart that reflects a general assessment of country capabilities is presented for each technology area. Although the ratings shown in these tables (see box) can never be precise, they do provide a general indication of the level of capability and therefore the relative priority of the opportunity in the technology or research areas. Countries with a four-diamond rating have capabilities generally on par with the United States. This implies that the country is a major contributor to global commercial device or system production, as well as databases and scientific literature. For example, in biomedicine, the pharmaceutical industry, medical diagnostics, food processing, and cosmetics industries represent the result of extensive economic investment by a nation. It is the combination of these capabilities, along with the demonstrated application of the technology and research toward areas of interest to the U.S. Army, that are reflected in a four-diamond rating. A single facility in a nation, be it developing or Third World, is not sufficient to identify the capability with four diamonds unless the facility is the site of world-class production or research in an area directly related to Army interests.

LEGEND FOR CAPABILITY TABLES

♦♦♦♦	**The country has strong and broad capabilities in most aspects of the major technology or research area. The country is considered to have world-class capabilities in the identified major area.**
♦♦♦	**The country has significant capabilities in some aspects of the major technology or research area. However, the country does not have the breadth or depth or capability to challenge world leaders in the area.**
♦♦	**The country has capabilities in a few niche aspects of the major technology or research area, but does not have broad capabilities. However, the niche capabilities could beneficially contribute to U.S. Army S&T activities.**
♦	**The country has limited capability in the major technology or research area.**

Note: Major technology or research areas are subgroups of one of the primary technology or research areas (e.g., Mathematical Sciences is a primary scientific research area and Applied Analysis is a major research area).

TRENDS

+	**Capability of country is increasing relative to global progress.**
–	**Capability of country is decreasing relative to global progress.**

Note: Trends are indicated only in cases where a significant capability change has been identified in a particular country.

The other diamond ratings reflect increasingly lower capabilities. A three-diamond rating implies that a substantial breadth of capabilities may exist, but the defense goals or commercial production in the area are not present. These nations may have a number of small facilities working across the area, but not at the scale of world leaders. A two-diamond rating indicates that the country has strong niche capabilities in the area. Often this rating indicates the presence of a small research group doing world-leading work in a nation where other capabilities in the area are limited. The one-diamond rating applies to a fledgling attempt by a nation to develop indigenous capabilities without any clear near-term commercial or military impact.

These tables are examples and are not intended to be all inclusive. The lack of an entry does not necessarily indicate the absence of cooperative opportunities; instead, it may be an indication of a lack of available data. Like S&T development, however, the data available to build this annex are dynamic and are updated annually.

B INTERNATIONAL COOPERATIVE OPPORTUNITIES IN TECHNOLOGY DEVELOPMENT

1 Aviation

AMC POC

Dr. Rodney Smith
e-mail: rsmith@hqamc.army.mil

IPOC

Mr. Dennis Earley
e-mail: dennis.earley@redstone.army.mil

Rotorcraft are of particular interest to the Army. Because of their ability to take off and land vertically and to operate efficiently and effectively at or below treetop level for nap-of-the-Earth missions, they offer a practical solution to many of the Army's operational needs. The operational flexibility afforded by vertical takeoff and landing (VTOL) capabilities has created growing civil and military markets, particularly in Third World nations. As a result, the helicopter industry has become highly internationalized and interdependent. Mergers and joint ventures have been, and will continue to be, in vogue. The West continues to dominate the rotorcraft industry. In addition to the capabilities in the U.S.–Canadian industrial base (Canada is closely aligned with the U.S. helicopter industry and therefore has similar capabilities), Germany, France, the U.K., Russia, and Italy are all capable of designing and producing state-of-the-art military rotorcraft. Additionally, helicopter programs are in place in other countries throughout the world (Japan, Malaysia, India, South Africa).

Hindustan Aeronautics Ltd. in India has experienced continuing delays and uncertainties surrounding its Advanced Light Helicopter project. Technical problems with engine-to-frame mismatch have delayed the program. In Russia, MIL Helicopter is facing bankruptcy. If this happens, it could affect the joint venture, Euromil, of MIL and Eurocopter S.A.

Eurocopter [http://www.eurocopter.com], a Franco–German company, claims to be the world's largest helicopter company and holds a 40 percent share of the world's civil market. The company is also active in the military market and gave the go-ahead to produce the Tiger, an attack escort helicopter, at the Paris Air Show in June 1999.

Although rotary-wing production through 2003 is forecast to be essentially level, militaries worldwide are cutting back on the number of new helicopters they buy. Two trends are emerging: consolidation of helicopter assets and emphasis on multimission helicopters. Purchases of mission-specific helicopters will be severely limited by cost factors.

Competition for international military sales is intense, and marketing rights and export prospects have affected development decisions, particularly in international programs. Such market forces continue to push worldwide developments. Helicopter emphasis will be on initial and operating cost reduction. Table E–1 summarizes potential air platform opportunities for international cooperation.

a *Aeromechanics*

Aeromechanics technology includes multidisciplinary efforts in acoustics, aerodynamics, rotor loads, vibration, maneuverability, and aeroelastic stability. A number of efforts are focused on reducing noise and vibration. The main source of external noise is blade vortex interaction (BVI), which occurs when a blade hits the vortex shed by the preceding blade. Current efforts to reduce BVI include developing low-noise flight profiles. Modifications to the helicopter are farther out. Scientists are focusing on three areas to reduce noise: tail rotor, main rotor, and cabin.

TABLE E–1. TECHNOLOGY DEVELOPMENT—AVIATION

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
AEROMECHANICS						
♦♦♦♦ Rotorcraft design	♦♦♦♦ Rotorcraft CFD Bearingless rotor hub	♦♦♦♦ Rotorcraft Bearingless rotor hub	*Japan* ♦♦♦ Rotorcraft CFD BVI	♦♦♦♦ Rotorcraft design	♦♦♦♦ Rotorcraft design	*Italy, Israel* ♦♦♦ Aeromechanical design
FLIGHT CONTROL						
♦♦♦♦ Fly-by-wire M&S Active control	♦♦♦♦ Adaptive controls Fly-by-light	♦♦♦♦ Fly-by-light	*India* ♦♦ Adaptive controls	♦♦♦♦	♦♦♦ Fly-by-wire	*Sweden* ♦♦♦ Adaptive controls *Netherlands* ♦♦♦♦
STRUCTURES						
♦♦♦♦ Composites Smart structures	♦♦♦♦+ C-C matrix ceramic Crash survivability ♦♦♦♦ Smart structures High temperature structures	♦♦♦♦ Smart structures Fatigue & fracture analysis	*Japan* ♦♦♦♦+ Ceramics Composite materials & structures *Korea* ♦♦♦ Smart materials & structures *India* ♦♦ Composites	♦♦♦ Ti & steel alloy structures	♦♦♦ Smart structures Fracture/fatigue analysis	*Italy, Switzerland* ♦♦ Smart materials & structures
SUBSYSTEMS						
♦♦♦♦ FADEC Direct voice input	♦♦♦♦ FADEC Advanced lightweight armor	♦♦♦♦ Advanced cockpit systems & integration	*Japan* ♦♦♦ Avionics	♦♦♦♦ Cargo handling Ceramic armor	♦♦♦♦ FADEC	*Israel* ♦♦♦ Advanced cockpit systems Lightweight armor
ROTORCRAFT PROPULSION/DRIVES						
♦♦♦♦ High performance transmission Advanced turbine design	♦♦♦♦ High-temperature structures Rotorcraft propulsion	♦♦♦♦ Composite & high-strength alloy shafting High-temperature gas turbines Rotorcraft propulsion	*Japan* ♦♦ Ceramics	♦♦♦♦ Small gas turbines High-temperature structures	♦♦♦+ Wind tunnel test facilities	*Israel* ♦♦ Small gas turbines
FUELS & LUBRICANTS						
♦♦♦ Coatings, hydraulic fluids & seals	♦♦♦ High-temperature lubricants, coolants & seals	♦♦♦ High-temperature lubricants, seals & coatings	*Japan* ♦♦♦ Seals & coatings			

Note: See page E–6 for legend.

Most of the effort is being concentrated in the main rotor, with individual blade control gaining more favor than higher harmonic control.

The French research organization, Office National d'Études et de Recherches Aerospatiales (ONERA) [http://www.onera.fr/english.html] and German Deutsche Zentrum für Luft- und Raufahrt e.V. (DLR) (Aerospace Research Establishment) [http://www.dlr.de/] are working on noise and vibration reduction, enhanced operating performance, and day/night, all-weather operations.

By adopting special features for the tail rotor, such as unequally spaced blades, advanced airfoils, modified blade taper, blade tip shapes, and blade tip speeds within the context of a "Fenestron" fan-in-fan design, noise from the source has been considerably reduced; the EC–135 employs these enhanced features. Engineers are now looking at additional Fenestron noise reductions. Eurocopter, with the Technical University of Aachen [http://www.rwth–aachen.de/zentral/aguid_english_default.htm] in Germany, has devised a network of Helmholz resonator passive-noise absorbers that they believe can resolve the problem.

The British Defence Evaluation and Research Agency (DERA) possesses a full range of rotor and control system modeling, simulation, and test and experimental facilities in the complex field of helicopter aeromechanics [http://www.dra.hmg.gb].

The National Aerospace Laboratory (NAL) in Japan [http://www.nal.go.jp] has performed work on the calculation of rotor BVI noise using parallel supercomputers.

Eurocopter is working on an advanced technology rotor with better aerodynamics, simpler blade attachments, and new materials. The use of a new fiber/matrix system with R-glass for the spar and cost-efficient 6K carbon fiber for the blade planking is thought to offer shorter production times and curing cycles, as well as better material characteristics.

b *Flight Control*

Flight-control technology defines the aircraft's flying qualities and the pilot interface. Helicopters are inherently unstable, nonlinear, and highly cross coupled. Advances in smaller, more powerful computers hold tremendous promise for realizing the full potential of the rotorcraft's performance envelope and maintaining performance even in poor weather and at night. Integrating flight control with weapons control to permit improved pointing accuracy and the use of lower cost, unguided rockets as precision munitions are of great interest. Other goals include improved external load handling at night and increased exploitable agility and maneuverability.

DLR (Germany), the German Ministry of Defense, Eurocopter [http://www.eurocopter.com] Deutschland, and Liebherr Aerospace Lindberg [http://www.liebherr.com] have designed a flying EC–135 testbed that incorporates advanced rotor and fly-by-light control technologies (along with state-of-the-art avionics concepts). They also have finalized the design of the combined active control technology (ACT) demonstrator/flying helicopter simulator. ACT is the enabling technology for improved performance and flying qualities of aircraft. Ongoing ACT research at DERA (U.K.) is identifying improvements in performance and reductions in attrition in future military helicopters.

To improve simulation modeling and control law design, DERA conducts high-fidelity experiments in flight using ground-based simulation, supplemented by in-depth theoretical studies. In addition, two facilities are operated for research into flying qualities and control: Aeromechanics Lynx Control and Agility Research Testbed (ALYCAT), and the Advanced Flight Simulator—a high-fidelity, ground-based simulator.

c *Structures*

Structures programs aim at improving aircraft structural performance while reducing both acquisition and operating costs. Virtual prototyping to optimize structural design for efficiency and performance is of particular interest as a means to remove a large portion of the risk involved in exploring new concepts and moving rapidly from concept to production. An inte-

grated product and process development approach will be used. Other areas of interest include reducing both dynamically loaded structural stress prediction inaccuracy and the production labor hours per pound for composite structures. Breakthroughs in these and other areas will lead to improvements in maintenance and production costs, as well as reduction of the empty weight fraction of the airframe, while increasing durability, performance, and ride comfort.

Advanced composite structures and fly-by-wire/-light are becoming common in international aircraft. Technologies for military systems reside primarily in the few countries that produce military helicopters. Predominant among these are France, Germany, the U.K., and Italy. Britain has strong capabilities in composites and smart structures; crash survivability is an area of special interest. France's expertise is generally on par with the United States in this area. Survivability depends on a number of factors, including equipment performance, which may be enhanced by more efficient design and testing of aircraft structures. Of particular interest is the testing of advanced structural concepts and manufacturing processes for composite and thermoplastic materials for primary helicopter airframe structures. Canada has strong capabilities in fracture/fatigue analysis, Russia in titanium (Ti) and steel alloy structures, and Japan in ceramics and composite materials.

DERA does significant research and experimentation in rotorcraft technology [http://www.dra.hmg.gb] that covers all aspects of aerodynamics and aeroelastic research into composite blade structures for optimum performance. The research addresses the structural design of blades, model performance trials and evaluation, validation of the theory and analysis of external noise research, and structural acoustics, including noise path identification and advanced statistical energy analysis. Scale rotor experiments are undertaken at a major hover test facility, where DERA also assesses rotor blade icing and the overall operational performance of rotorcraft. MSC.Nastran and MSC.Dytran finite-element-analysis software, various pre- and post-processors, and Structural Analysis and Redesign System structural design optimization packages are available.

DERA is at the forefront of research into lightweight material technologies. This research aims to reduce the observability and weight of airborne structures while providing high strength. High-temperature operation is also important, especially for future high-performance engines.

Virtually all countries with any level of industrial development have national nondestructive evaluation (NDE) organizations and some level of university research. The following highlight some of the more relevant capabilities identified:

- *Germany*—The helicopter manufacturer Messerschmitt–Boelkow–Blohm (MBB) is an active participant in a number of Basic Research for Industrial Technologies in Europe—European Advanced Materials (BRITE/EURAM) initiatives related to NDE for composite structures.
- *Italy*—Particularly relevant effort is directed toward NDE for composite materials and toward rotorcraft applications. Among the key players in government and academia are the Italian Center for Aerospace Research and the University of Rome. In the private sector, Ispra appears to be heavily engaged in a wide range of research activities, including laser ultrasonic techniques and the use of combined acoustic emission and thermographic techniques. Italy is also a partner in BRITE/EURAM projects in which the Italian helicopter manufacturer Agusta has the lead. (As noted, other participants in these programs include MBB (Germany) and Westland (U.K.). Fiat Aviazione is also reported to be working in composite material NDE.)
- *United Kingdom*—Extensive research is conducted in areas of NDE relating to aerospace applications. The British Institute for Nondestructive Testing and a number of government and university centers of research are very involved. Work at the University of Strathclyde, Glascow, Ultra-

sonics Research Group is often cited as world class by other researchers. In the private sector, the U.K. helicopter manufacturing firm Westland is actively involved with BRITE/EURAM activities, principally in cooperation with Agusta (Italy) and MBB (Germany).

- *France*—ONERA and Aerospatiale have active research in composite materials and NDE, and work in impact damage to polymer-based composite at Aerospatiale may provide access to empirical data. French organizations do not appear to be as well represented in the BRITE/EURAM programs or as extensively referenced by researchers in other countries.
- *Japan*—Much of the NDE-related work in Japan is focused on microelectromechanical systems (MEMS) and on composite materials with novel electronic or optical sensing properties. These areas directly related to rotorcraft NDE include (1) eddy current and electrical potential measurement inspection techniques for detecting delamination defects in carbon fiber reinforced plastics and graphite-epoxy structures, (2) sensor techniques for monitoring of airframe repair patches, and (3) research in applications of optical fibers for structural monitoring and fault detection.
- *Canada*—Work at the Institute for Aerospace Research (IAR) under the Canadian National Research Council is developing NDE techniques, including what is described as a "highly portable" ultrasonic scanning system capable of real-time evaluation of an area of 0.45 × 0.45 meter. There may be operational advantages to areal measurements (as opposed to testing at specific points), particularly if the size can be extended to several meters to permit inspection of large portions of an airframe.
- *Korea*—Although specific expertise in NDE has not been identified, much of the Korean academic research in smart materials and structures is directed toward technologies for rotorcraft applications. These may provide useful information for characterizing airframe response and for design of embedded actuators and sensors to support more advanced NDE capabilities in the future.

An area of specific interest to the Army is the application of smart materials and structures to rotorcraft.

- *Germany*—Germany is one of the European Union (EU) leaders in smart materials and structures and an active participant in EU-sponsored programs. German academic and research work generally recognized in the field includes (1) University of Saarlandes and the Technische Hochschule at Darmstadt, both of which participate in the University of Patras program in generic smart surfaces for vibration and acoustic control; and (2) Fraunhofer Institute for Ceramic Technologies and Sintered Materials [http://www.ikts.fhg.de] in Dresden conducts an extensive program of research in piezoelectric ceramics and new applications of such materials in various technical areas.
- *United Kingdom*—Both academia and private industry participate in smart materials and structures programs. Participation in the BRITE/EURAM-sponsored activities pertinent to smart structures provides an insight into the breadth and depth of U.K. capability. The EU has funded development of advanced electrorheological fluids and devices at the University of Hull. Hull is a participant in the BRITE/EURAM-sponsored work in the optimization of smart structural connections for vibration and noise control. Work in applications of electrorheological fluids for vibration control and isolation is also reported in the U.K. at the University of Manchester and Gordon University.
- *Italy*—Substantial research in sensing and smart structures is centered throughout government, academic, and private industry participants. Much of the work in materials and sensors is directed toward NDE. However, much of the underlying technology, such as the BRITE/EURAM III initiative in magnetostrictive actuators for damage analysis and vibration control at the University of Naples, is directly applicable to smart structures. This work is of interest because it may develop alternatives to the piezoelectric and other electroactive ceramic techniques being stressed by other centers, particularly in applications requiring high authority over a wide frequency range. The Italian Center for Aerospace Research is a participant in the BRITE/EURAM III project in active vibration control of surfaces headed by the University of Patras (Greece).
- *France*—Research programs in vibration control and NDE are conducted by government institutes, academic institutes, and private industry, all of which participate actively in European

research initiatives relating to smart materials and structures. At this juncture, they do not appear to be applying the technology as aggressively as the U.K., Germany, and Italy.

- *Canada*—The Canadian National Research Council conducts and coordinates a wide range of programs in basic materials (including rheological studies and piezoelectrics), as well as related work in vibration analysis and control applicable to characterization of smart structures. The Center for Research in Earth and Space Technology reports an effort in smart adaptive structures focused on potential applications to aircraft, bridges, space structures, and pressure tanks. The development of fiber-optic sensors that are integrated with a host structure are a precursor to the broader development of smart adaptive structures.
- *Japan*—Cited as being on par with the United States as a world leader in smart materials and structures, Japanese research areas of interest include smart polymeric composites with applications to infrastructures and ground and aerospace vehicles; shape memory alloy (SMA) materials and their composites; smart materials based on the coupling behavior between physical and mechanical phenomena; piezoelectric, piezoresistive, magnetostrictive, and their composite materials and structures where the stress and strain are key driving or resulting parameters; and novel electronic and optical composite materials with unique sensing capabilities. Much of Japan's most advanced capability is directed toward MEMS and electronic sensor applications.
- *Switzerland*—The work at the University of Lausanne covers a wide range of topics of interest, including work in the bismuth titanate family of piezoceramic materials (which are of interest for high-temperature applications) and in lead zirconate tinanate for high-frequency use. In addition to basic materials, other research includes fabrication technology (for piezoelectric and ferroelectric microtubes), application of thick-film screen printing techniques to fabricate zirconate tinanate sensors and actuators, and development of smart structures. Here, Swiss researchers report better than 20-dB active vibration damping in composite metal-ceramic structures. The Ecole Polytechnique Federale de Lausanne is also cited as a contributor to the BRITE/EURAM-sponsored British Aerospace, Plc., investigation of MEMS for boundary layer control in airfoils.
- *Greece*—One of the more interesting and relevant of the BRITE/EURAM efforts is investigation, headed by the University of Patras, of generic approaches to active vibration control of smart surfaces. This work is directed at the use of artificial neural networks (ANNs) and genetic algorithms for smart structure controls for a variety of aerospace and industrial applications.
- *Korea*—Both the Pohang University of Science and Technology (POSTECH) in Pohang, South Korea [http://www.postech.ac.kr/e] and the Seoul National University conduct research programs in smart structures. Topics include the use of electrorheological fluids for damping and integration of feedback control and advanced composite material technologies with the design of high-performance structural systems. The stated objectives of the research are to design and develop structures that are adaptable and responsive to external disturbances, especially for aerospace applications. POSTECH appears to be a center of Korean research in rotorcraft technology.

d *Subsystems*

Rotary-wing vehicle subsystems encompass a broad range of S&T topics related to support, sustainment, and survivability of aircraft systems and their associated weaponry. Germany, Japan, and Israel all have strong capabilities in advanced cockpit systems, but the German work on cockpit integration is of special interest. The U.K. is doing significant work on full-authority digital engine control (FADEC). Japan has strong capabilities in avionics, based on its significant electronics capability.

Lightweight armor for rotorcraft is an area of particular interest to the Army. Japan, Germany, the U.K., and France have been identified as having the capability for producing advanced armor systems. Russia has been a traditional force in armored systems and in bulk ceramics. The materials are widely available, and other countries—notably the Netherlands, Israel, China, Sweden, and Switzerland—have sufficient experience and resources to develop effective systems. Applications of ceramics or fibers to armor systems can be found in Germany, the U.K.,

France, the Netherlands, China, and Israel. Israel has extensive experience in armor design and testing and has a number of firms actively involved in developing and marketing lightweight armor.

Israeli capabilities represent an example of the type of activity and products occurring in many countries. Rami Ceramic Industries advertises a wide range of armor products, including lightweight ceramic armors for helicopters. They advertise lightweight, impact-resistant ceramic plates capable of meeting stringent military standards (U.S. National Institute of Justice (NIJ) Std 0101.02 and 0108.01 and MilStd.662D).

e *Rotorcraft Propulsion/Drives*

Propulsion, drive train, and power transfer research is required to lower weight, volume, noise, and increase durability. The U.K. has strong capabilities in high-performance power transmission technologies. DERA has an experimental capability for validating the theoretical methods and exploring the application of advanced technology rotor systems. This capability is provided by a Mach-scaled model rotor rig that, combined with a purpose-built hover facility used with the DERA 24-foot and 5-meter wind tunnels, forms an integrated test capability covering the flight envelope of the helicopter.

France has expertise in bearingless rotor hubs, as does Germany. Germany also has noteworthy capabilities in composite materials and high-strength alloy shafting. The Sadlier VTOL Aircraft Company Pty., Ltd., of Australia is considering a vertical takeoff aircraft that would combine the properties of fixed-wing and rotary-wing aircraft. It has a fan in the wing and a rear fan. It employs a diamond-shaped lift system with a single lift rotor at the center of the fan.

Unmanned aerial vehicles (UAVs) contribute to the military's effectiveness by providing tactical and strategic reconnaissance. The number of countries using UAVs or funding development programs or both has doubled since 1991. There is a mix of large and small industry players, partly because of increasing strategic alliances, industrial cooperation, and teaming arrangements.

- *France*—CAC Systems has teamed with Dragonfly (Italy) to produce the Heliot unmanned helicopter system with a 100-kg pod payload. In addition to cooperative work with the U.S. Air Force Research Laboratory on an unmanned combat air vehicle (UCAV), ONERA is working on exploratory studies for a high-altitude, supersonic, stealthy UAV for reconnaissance and electronic warfare.
- *Germany*—UAVs are used for reconnaissance and for communications jamming at up to 100-km. Schiebel Technology, Inc., has demonstrated its Camcopter airborne optical minefield survey system, which for over 2 years has detected buried landmines 2–6 inches deep with a gimbaled IR camera.
- *United Kingdom*—DERA is developing a remote minefield detection payload for the Phoenix UAV system, which entered service in December 1998. Other payloads envisioned include a miniature synthetic aperture radar, multispectral IR/visual imager, laser designator for attack helicopter targeting, and acoustic/chemical sensors. DERA is also looking at UAVs as potential communications relay platforms.
- *Canada*—Orenda Aerospace and the Department of National Defence are developing an engine-life management system, including structural and thermal models, that is geared to optimizing maintenance and repair schedules for aircraft.

All conventional rotary-wing aircraft have a forward speed at which drag, vibration, and loss of lift reach unacceptable levels, limiting any further increase. One approach to dealing with this

problem is to tilt the rotors through a right angle so that for vertical takeoff they are horizontal until sufficient height is attained. Transition to forward flight is achieved by tilting the rotors to the horizontal. In forward flight, the fixed wing provides lift. To enable increased loads to be carried, the rotors may be set at a midway position, clearing the ground, so they provide both thrust and lift, while the fixed wing also provides lift. Thus configured, a very short takeoff run is needed to appreciably increase lifting power.

A significant advantage of the tilt-rotor layout over the helicopter is that, whereas the rotor blades of a "pure" helicopter must have relatively little twist (the difference between root and tip angles-of-incidence)—say, about 12 degrees—the blades of a tilt-rotor aircraft may have as much as 40 degrees twist. Thus, these blades are very efficient whether generating lift for vertical flight or hovering or thrust for forward flight.

The proof of the efficacy of the tilt-rotor configuration is that, of all the design layouts tested with prototypes, only the helicopter, vectored-thrust fighter, and tilt-rotor have entered production. In late 1987, the European Eurofar tilt-rotor project was launched as a preliminary plan by Eurocopter (France and Germany), Aerospatiale (France), Agusta and Alenia (Italy), Westland in England, and CASA in Spain. The specification was for a 30-passenger commercial aircraft with a range of 664 nmi (1,230 km) at a cruising speed of 335 knots (620 km/hr). The project was backed by extensive wind-tunnel aerodynamic and aeroelastic testing, simulated flight control, and a full-scale, pressurized fuselage cabin section.

Matching U.S. plans, a Eurofar civil tilt-rotor aircraft—smaller than a derivative of the Osprey—could be flying within 12 years. This would require the Eurofar demonstrator to fly in 2004 and the ground-test article (Iron Bird) to begin spin-up tests 2 years earlier.

f ***Fuels and Lubricants***

The Army's main interest in the fuels and lubricants subarea is the development and validation of new analytical technologies. Of particular interest are techniques for rapid assessment of petroleum quality using spectroscopic and chromatographic methods. New analytical methods will enable a significant reduction in operational requirements for petroleum field tests. This includes less manpower, test time, and test hardware. Technical challenges relate to compressing testing time, developing improved detection systems, correlating testing results, and developing computer-based expert systems. In this subarea, France and Germany are the only countries found to have special capabilities, both in the area of high-temperature lubricants.

All countries engaged in the operation of military weapons and systems use fuel and lubricant technologies to some degree or another. To a great extent, civil sector products can be used successfully in military systems but not at the outer bounds of their operational envelopes. Much of the work involved in development and production of these materials depends on a sophisticated chemical industry. Thus, all industrialized nations, and many developing ones as well, have capabilities in special functional materials. Particularly noteworthy are France in engine coolants, lubricants, and seals; Germany in seals and coatings; the U.K. in coatings, hydraulic fluids, and seals; and Japan in seals and coatings. These countries can approach or duplicate U.S. technology in these areas.

g *Example Research Facilities*

The following facilities have demonstrated expertise in aviation technology development:

- Japan—National Aerospace Laboratory [http://www.nal.go.jp]
- France—The French Aeronautics and Space Research Center, ONERA [http://www.onera.fr/english.html]
- Canada—Institute for Aerospace Research [http://www.nrc.ca/iar]
- Europe—Eurocopter [http://www.eurocopter.com/]

2 Command, Control, Communications, and Computers

AMC POC

Dr. Rodney Smith
e-mail: rsmith@hqamc.army.mil

ARL IPOC—Computers & Software Technology & C^3

Mr. Stephen Cohn
e-mail: scohn@arl.army.mil

IPOC—M&S

Mr. Gene B. Wiehagen
e-mail: gene_wiehagen@stricom.army.mil

Several approaches are being considered for Information Systems, each of which (if ultimately realized) is likely to offer advantages for different applications. High-performance computing (HPC) and scalable parallel systems are of particular importance. For example, optical processing techniques combine elements of both and are being pursued as a means of increasing inherent parallelism and computational throughput. Further, software advances are seen as a way to allow aggregation of very large numbers of computing elements. Both of these approaches lend themselves to solving complex deterministic problems (i.e., problems for which a sequence of calculations to reach a specific solution can be defined). Contrast this to neural networks, which provide a better way of attacking less determinate problems.

Even though military applications will increasingly rely on COTS products, there remain unique requirements for which technological advances in computing hardware and software will be required. These advances fall into the realm of HPC, the so-called "grand challenge," which requires trillions of floating point operations per second (teraFLOPS). This section partitions Information Systems into three areas (which are further subdivided): computers and software technology; command, control, and communications; and modeling and simulation.

Integration and demonstration of technology in the field are significant challenges. Widespread mass market availability of low-cost computers of unprecedented power and global connectivity over the Internet has led to rapid expansion and proliferation of information system technologies. COTS software is also readily available throughout the world, some of it being customized to large applications.

HPC is an area of international R&D. In addition to France, which is recognized as a world leader in photonics, Japan and Russia have had strong programs in optical computing. Germany has a growing interest and has strong capabilities in production of photodynamically active bacteriorhodopsin films that may be an enabling technology for future optical/molecular computers. Israel has a small but sound and growing electro-optics infrastructure as well. The growth of the Internet and multimedia are producing growing demand for development and global implementation of very high-speed digital networks. Development of these is an international activity, with cooperation among major telecommunications firms. One example is the Japanese Real-World Computing program, which includes a number of other countries as participants. Table E–2 summarizes international information systems technology capabilities.

TABLE E–2. TECHNOLOGY DEVELOPMENT—COMMAND, CONTROL, COMMUNICATIONS, AND COMPUTERS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
COMPUTERS & SOFTWARE TECHNOLOGY						
HIGH-PERFORMANCE COMPUTING & SCALABLE SYSTEMS						
♦♦♦♦ MPP	♦♦♦♦ Optical processing	♦♦♦♦ MPP	*Japan* ♦♦♦♦ *China* ♦♦+ *Taiwan* ♦♦	♦♦– Optical processing		
NETWORKING						
♦♦♦♦ Optical switching	♦♦♦♦ Fiber optics	♦♦♦♦ Fiber optics	*Japan* ♦♦♦♦ Optical switching *China* ♦♦ Fiber optics		♦♦♦♦ Optical switching	*Israel* ♦♦ Fiber optics
SOFTWARE ENGINEERING						
♦♦♦♦	♦♦♦	♦♦♦♦ MPP	*India* ♦♦♦ CASE		♦♦♦♦ CASE	*Israel* ♦♦♦ CASE
ARTIFICIAL INTELLIGENCE						
♦♦♦♦	♦♦♦♦	♦♦♦♦	*Japan* ♦♦♦♦	♦♦	♦♦♦	
COMMAND, CONROL, AND COMMUNICATIONS						
HUMAN–COMPUTER INTERFACE						
♦♦♦♦ Visually coupled systems	♦♦♦♦ Visually coupled systems	♦♦♦♦ Visually coupled systems	*Japan* ♦♦♦ Visually coupled systems		♦♦♦♦ Visually coupled systems	*Italy* ♦♦♦ *Israel* ♦♦♦
SEAMLESS COMMUNICATION						
♦♦♦♦ Battlefield interoperability	♦♦♦♦ Battlefield interoperability	♦♦♦♦ Battlefield interoperability, international interoperability	*Japan* ♦♦♦♦ Fuzzy logic High-speed communications *ROK* ♦ Systems interoperability		♦♦♦ Tactical interoperability	
INFORMATION MANAGEMENT ASSURANCE AND DISTRIBUTION						
♦♦♦ Natural language processing	♦♦♦ Machine translation	♦♦♦♦ Natural language processing, machine translation	*Japan* ♦♦♦♦+ High-speed switching *ROK* ♦ Data fusion		♦♦♦ Advanced data display	*Netherlands* ♦♦♦ Natural language processing Database science

TABLE E–2. TECHNOLOGY DEVELOPMENT—COMMAND, CONTROL, COMMUNICATIONS, AND COMPUTERS (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
			DECISIONMAKING			
♦♦♦♦ Mission planning	♦♦♦ Mission planning		*Japan* ♦♦♦ Fuzzy logic			*Israel* ♦♦♦ Battle management
			MODELING & SIMULATION			
			SIMULATION INTERCONNECTION			
♦♦♦♦+ Distributed information systems	♦♦♦♦ Distributed information systems	♦♦♦♦+ Distributed information systems	*Japan* ♦♦♦♦+ Distributed enterprises			*NATO* ♦♦♦♦+ *Australia, New Zealand* ♦♦♦♦
			SIMULATION INTERFACES			
♦♦♦♦+ VR	♦♦♦♦+ VR	♦♦♦♦+	*Japan* ♦♦♦♦+ VR		♦♦♦♦+ VR, 3D	
			SIMULATION INFORMATION			
♦♦♦♦+ Dynamic training	♦♦♦♦ Dynamic training	♦♦♦♦+ Battle M&S	*Japan* ♦♦♦♦+ VR		♦♦♦ Battle M&S	*Netherlands* ♦♦♦ Battle M&S
			SIMULATION REPRESENTATION			
♦♦♦♦	♦♦♦♦	♦♦♦	*Japan* ♦♦♦ Distributed enterprises		♦♦	*Netherlands, Switzerland* ♦♦

Note: See page E–6 for legend.

a *Computers and Software Technology*

The United States dominates and is projected to continue to drive the state of the art in HPC; Japan has strong capabilities. The United States has pioneered a variety of technologies for scalable, distributed processing based on U.S. microprocessor designs in which computational power continues to double approximately every 18 months. These configurations now dominate the market. Availability of an affordable HPC capability has also led to a growing level of international interest and work in intelligent systems and human–computer interfaces.

Massively parallel processing (MPP) and neural network programming could be applied to numerous applications covered by ASTMP milestones and objectives. Modeling and simulation are examples of applications requiring the computing speed and power offered by MPP techniques, while neural network programming may be more useful in the development of decision aids. MPP and neural network programming are important aspects of the Army's electronic battlefield concept. MPP will contribute significantly to simulation and VR components of the electronic battlefield. Only a few countries have the supporting infrastructure necessary for major R&D in these technologies. World leaders include the United States, Japan, Germany (with whom an active data exchange agreement exists), and to a lesser extent the U.K. and France.

Military requirements for processing real-time signals and imagery data severely challenge existing computing capabilities. Optical processing offers potential advantages for these

applications and is an important area of technology development where other nations have world-leading capabilities.

1) High-Performance Computing and Scalable Systems

Mass market availability of low-cost network switching and powerful microprocessors resulted in rapid proliferation and expansion of capabilities for HPC. Nearly all of the requisite knowledge and software technology required for clustering computers to achieve high performance is in the public domain. For example, the NASA-supported Beowulf program provides access to detailed guidance and software for assembling a computing cluster; the software itself can be downloaded.

As a result of the increased accessibility of the technology, the number and diversity of activities involved in HPC have increased dramatically. The following paragraphs highlight some specific examples of recognized centers of excellence in HPC research.

In France, the Institut National de Recherche en Informatique et en Automatique (INRIA) is the primary focus of computing research. Primary research is organized in five major strategic areas: control of distributed computer information, programming of parallel machines, development and maintenance of safe and reliable software, construction of systems integrating images and new forms of data, and analysis, simulation, control, and optimization of systems.

The German National Research Center for Information Technology (GMD) oversees and coordinates research in a number of areas of interest, including basic architecture and software research, autonomous intelligent systems, scientific computing, and distributed collaborative computing. The Universities of Mannheim, Karlsrhue, and Paderborne are all recognized centers of excellence in HPC.

The European Research Consortium for Informatics and Mathematics (ERCIM) comprises leading research establishments from 14 European countries. ERCIM aims are to foster collaborative work within the European research community and to increase cooperation with European industry. ERCIM's collaborative activities also extend beyond the EU. The European Commission has awarded ERCIM a grant to coordinate an EU–China industrial cooperation initiative in HPC. The initiative is also partially financed by the Chinese government through China's National Research Center for Intelligent Computing System (NCIC), with additional funding coming from European and Chinese industry. The goal is to promote Sino–European cooperation by raising Chinese awareness of EU technologies and expertise and to inform the EU business community about market opportunities in China. Participants in relevant European Strategic Program for Research in Information Technology (ESPRIT) projects will be invited to take part. This HPC initiative is part of a range of EU–China industrial cooperation activities in S&T now being organized under the auspices of the Chinese government and the European Commission.

The NCIC was founded in March 1990 under the leadership of the Steering Committee of National High-Tech R&D Program (the so-called 863 program) on Intelligent Computing System. NCIC's R&D activities in HPC include parallel and distributed computers and fundamental research on high-performance computers and intelligent computing systems, especially in the area of natural language interface. Although one of NCIC's goals is to develop competitive commercial computer products, results to date appear better suited to developing a fundamental understanding of the underlying technology than global commercial competition. The

"Dawning" family of parallel computing hardware trails the state of the art in terms of its embedded microprocessor and interconnect technologies. However, as research tools, these projects have provided a foundation for investigating effective parallel computing methods.

Research that may have application for the Army is intelligent machine translation research within the areas of theoretical research, system design, and product development of intelligent machine translation systems.

CANADIAN CENTERS OF EXCELLENCE

High-Performance Computing Facility, University of Victoria

Multimedia Advanced Computational Infrastructure, University of Alberta

University of Calgary, University of Lethbridge, University of Manitoba

Physical Science Computer Network, University of Toronto

Interdisciplinary Research Facility for Innovative Applications of Information Technologies, Concordia University

Réseau Québécois de Calcul de Haute Performance, Université de Montréal, Centre de Recherche en Calcul Applique, Université de Sherbrooke, with research centres at École polytechnique, McGill University, Université de Québec à Montréal, and Concordia University

Advanced Computation and Visualization Centre, Memorial University of Newfoundland, University of New Brunswick (Fredericton), University of Prince Edward Island, St. Francis–Xavier University

Canada has a strong initiative in distributed HPC. The Canadian telecommunication firm Nortel is a world leader in fiber-optic switching technology, and Canada has established what is advertised as the world's first national optical R&D network, CA*net3. C3.ca is a 7-year plan to build a computational infrastructure that supports globally competitive R&D. Canada's HPC community includes research facilities worth over $70 million. The project will receive $23 million in capital from the Canada Foundation for Innovation. Six universities and regional consortia, which are all C3.ca members, were approved for Canada Foundation for Innovation funding to establish facilities for computation and visualization, including approximately a dozen parallel, shared memory, and vector systems for advanced computing and six new multimedia visualization centers.

Research initiatives of interest to the Army include parallel/distributed intelligent agents, virtual prototyping M&S, and a wide range of software research activities in parallel and distributed computing.

2) Networking

Optical-processing techniques are well suited for analysis of data generated by these high-volume throughput applications. The development of photonic devices necessary for optical computing is of significant interest to the U.S. Army and has numerous military applications. World leaders in photonics/EO include the United States and Japan, followed by France, the U.K., and Germany. Before the breakup of the FSU, Russia and its allies had a rigorous program in biomolecular/optical computing. The apparent intent of this effort was to develop a leap-ahead technology to overcome the commanding U.S. lead in conventional digital computing. Although the military imperative for this has diminished, the technological capabilities may still be of interest.

The network throughput demands of international telecommunications firms are primary drivers of the state of the art in most networking areas, among them fiber-optic communications and optical switching (including wave division multiplexing techniques). All of the major telecommunications producing nations—the United States, the U.K., Japan, France, Germany, and Canada, followed closely by China and Israel—have good capabilities in fiber-optic networks. The implementation of the 5–10-Gbps fiber-optic cable that will link Europe and intermediate points in Africa and Asia with Japan will almost certainly speed proliferation of this technology.

While Japan and selected regions of Europe may lead in deployment of high-speed, fiber-optic cables, implementation in other areas is limited primarily by economic considerations rather than by technology. In the critical area of switching, the United States, Canada, and the U.K. have the strongest technological positions, followed very closely by Germany and France.

Comprehensive management of networks is very important. The integration of data and telecommunications networks—from narrowband to broadband, terrestrial to satellite, fixed to mobile—used for standard and advanced multimedia communications is a growing need. Commercially, there is a new emphasis in electronic commerce, federated systems, and end-to-end management of distributed services. The Army has a greater need for network survivability, fault tolerance, and availability than most commercial users, but the demand is rising for these attributes in some commercial sectors, such as banking and stock trading. Even more than commercial sectors, the Army has a high demand for technologies to provide communications in a degraded mode, such as under battlefield and crisis situations. Thus, not all technologies to support Army networks can be drawn strictly from commercial sources. Adversaries often are better able to operate in degraded mode because they lack of dependence on modern technology. Dynamic management and resource allocation are key to providing Army superiority.

3) Software Engineering

International software developments are enabled by widespread availability of very powerful microprocessor-based, symmetrical multiprocessing systems. A number of countries, including Israel, India, and Russia, are actively engaged in commercial cooperative software developments.

One key to achieving Army goals for M&S is the implementation of advanced algorithms in software, specifically for MPP. Only a few countries possess the supporting infrastructure necessary for major R&D in this area. World leaders include the United States, Japan, Germany (with whom there is an active agreement), the U.K., and France.

Software engineering development methodology is primarily a U.S. area of research. However, software development processes have proven to be more profitable commercially than new research in methodology. Thus, countries that have a culture of strict adherence to process are better able to produce quality software than many U.S. companies. A notable example is India.

4) Artificial Intelligence

Machine intelligence is an underlying technology for many advanced HCIs. Topics such as natural language processing, intelligent adaptive data visualization, and others properly fall into both categories.

AI (or machine intelligence or intelligent systems) is an area of worldwide research interest. One area that is particularly promising for international collaboration is artificial neural networks (ANNs) (e.g., the optical ANNs being pursued by Japan as part of the Real-World Computing (RWC) program initiative). Another area is the application of AI to so-called intelligent agents for collecting information and managing operations in a distributed battlefield C^4I and information system. For example, Australia has a particularly strong presence and activity on the Web. Much of the work is theoretical in nature, and many of the problems are tractable with modest computing power that is widely available in the commercial market. This active and effective research in AI can be found in most developed or developing countries. Much of this work is being driven by the Internet or by requirements for managing and administering extremely

large, complex telecommunications systems. In addition to work in the United States, which is the world leader in this area, Japan's RWC initiative has a strong component of AI. Strong capabilities in intelligent agents also reside in the U.K. and Germany, followed closely by France.

Foreign countries with the highest potential for implementing AI and intelligent systems are those that have a strong background in systems technologies, AI logic, and enabling technologies: Japan, the U.K., France, Germany, followed closely by the Netherlands and Canada, and to a lesser extent Sweden. Other countries with niche capabilities in specific areas that might provide cooperative program opportunities include Israel; other European community (EC) countries, such as Italy and Belgium; and Pacific Rim nations, such as Australia, Korea, New Zealand, Singapore, and Taiwan.

Japan has significant capabilities in AI. The most prominent efforts are the Fifth-Generation Project and the RWC program. The developmental side of the Fifth-Generation effort took place at the Institute for New-Generation Computer Technology, using PROLOG and specially designed hardware. Although the effort resulted in world-class capabilities in constraint programming (logical programming used for solving nonlinear problems) and nonlinear programming, it had little impact on the development of intelligent systems because of the rapid advance in general-purpose computing and growth in the use of C and other languages for implementing intelligent capabilities.

Japan's Ministry of International Trade and Industry initiated a major effort in 1992 with the RWC program. This 10-year, $500 million program emphasizes development of technologies matching human capabilities in information processing, namely pattern recognition and handling of incomplete information. Research is aimed at four areas: novel functions (e.g., fuzzy logic, neural logic, genetic algorithms), theoretical applications, massively parallel and distributed computing systems, and optical computing systems. Unlike the Fifth-Generation Project, the RWC program is an international effort involving the United States, the EC, Canada, Singapore, Sweden, and others.

In 1989, the Ministry of Information and Technology Integration funded a 6-year project called the Laboratory for International Fuzzy Engineering Research to consolidate and propel research into fuzzy logic. A large portion of this research is focused on developing capabilities in control systems and interfaces, computer vision and intelligent robotics, decision support systems, and fuzzy computing (e.g., fuzzy associative memories). Though originally a U.S. technology, the Japanese, through continued interest and funding, now dominate the market (80 percent market share) for fuzzy logic devices.

In addition to their extensive research, the Japanese have successfully applied fuzzy logic to a wide range of applications, from energy optimization and improved control of alternating current induction motors, audio and video compression, engine control, and robotic arm movement to visual sensor and mechanical motion coordination. Increasingly, fuzzy logic is being used for computer vision, personal computing, and telecommunications (including mobile networks).

Japanese industry has been pursuing the commercial use of neural networks since 1988, with the first commercial products reaching the market in 1990. Most of these products incorporated neural network components for self-correction of fuzzy logic process-control signals. Products incorporating neural networks include air conditioners, electric fans, heaters, refrigerators,

microwave ovens, photocopying machines, and washing machines. The combination of fuzzy logic and neural logic is commonly referred to as "soft" computing.

European countries have pursued development of intelligent systems capabilities through the EC and nationally funded efforts. These efforts have resulted in significant capabilities in AI logic and enabling technologies critical to the development of intelligent systems. This, along with their advanced supporting technological infrastructures and the economic aspect of a united Europe, will make cooperation both feasible and desirable.

Europe presents a special challenge when trying to evaluate foreign capabilities. Taken individually, many European nations have niches of excellence in specific AI and intelligent systems technologies. At face value, these capabilities could lead to a low assessment of their ability to develop large-scale, complex systems. What this fails to appreciate, however, is the unifying structure of the EC and its broad-ranged, large-scale dedicated R&D efforts. A major objective is to enhance European capabilities, thereby reducing technological dependence on the United States and Japan. With this in mind, the following paragraphs first discuss the EC initiatives, followed by individual country assessments.

Several efforts in intelligent systems are being pursued by multinational organizations under the sponsorship of the EC:

- The European Software and Systems Initiative is made up of large European hardware producers, national institutes, and software houses. Its goal is to improve software productivity and assist in the transfer of existing software tools and methods to users.
- The European Coordinating Committee for Artificial Intelligence (ECCAI) was established in 1982 as a representative body of the European AI community. Its aim is to promote the study, research, and application of AI in Europe. ECCAI has 11,000 members from Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, the Netherlands, Norway, Portugal, Russia, Slovenia, Spain, Sweden, Switzerland, and the U.K.
- The European Research Coordination Agency (EUREKA) has sponsored a number of programs to develop advanced software technology. Several software development tools created under this program are now commercially available.
- The Fourth Framework program (1994–98) is the largest effort for promoting and funding research within the EC, both in terms of funding and range of research. The principal objective is to encourage cooperative research and technological dissemination between enterprises, research centers, and universities within the EC, as well as development of cooperative programs with non-EU members. Related to intelligent systems R&D, $3.4 billion ECUs have been allotted under the Framework program for development of information and communications technologies and $2.0 billion ECUs for the development of industrial technologies. These areas constitute nearly half of the total $11 billion ECU effort. Research into information technologies sponsored by the Framework program falls under the purview of the ESPRIT program, which sponsors research by means of individual projects, working groups, and networks of excellence.

The non-EC-sponsored European Computer Industry Research Center (ECRC) is dedicated to promoting technological development related to intelligent systems. ECRC was founded in 1984 by Bull SA (France), ICL (U.K.), Plessey (U.K.), and Siemens AG (Germany). This organization promotes the development of information technologies in areas of strategic interest for European industry and in emerging applications.

European countries typically are strong in the theory and application of neural logic, weaker in fuzzy logic and genetic algorithms, and very weak in CASE-based reasoning. The most notable development in genetic algorithms has been the Programming Environment for Applications of

Parallel Genetic Algorithms project, a combined effort by France, Germany, the U.K., and the Netherlands, to develop a common programming environment for the development of parallel genetic algorithms.

EC ORGANIZATIONS WITH AI LOGIC CAPABILITIES

CompulogNet—Dedicated to all aspects of computational logic including machine learning, constraint logic, and its applications to natural language programming

MLnet—The machine learning network of excellence started in 1994, coordinated by the GMD

EvoNet—Network dedicated to research into evolutionary computing

ERUDIT—European network in developing capabilities to handle uncertainty in information systems technology

NEURONET—Neural network of excellence, started in May of 1994, with the objective of coordinating neural network research and expanding capabilities in theory, applications, and implementation

The U.K., Germany, and France have pursued neural logic actively to support development of indigenous electronics capabilities. Neural network research is being pursued primarily at theoretical (design and modeling) and exploratory (simulation) levels. European capabilities in theoretical research are considered on par with the United States, but trail in applied research. Simulation efforts have largely been handicapped by a lack of hardware and software for effective real-time implementation of neural networks.

The EC has been instrumental in promoting the development and transfer of enabling technology among member states. One notable project was the Portable Common Tool Environment. This interface, which makes any CASE toolset platform independent, is being promoted as a European standard. A related effort, EUROWARE, is promoting the large-scale (Europe-wide) development of software reuse technology. The principal participants in EUROWARE are France, Italy, and the U.K.

DERA is the main organization of the Ministry of Defence in the U.K. under which military R&D is conducted. DERA is the principal organization for the operational system R&D. This agency has several groups doing intelligent systems research on computer vision, image processing, image interpretation, and pattern processing. The British government is also pursuing a large-scale, indigenous commercial effort into intelligent systems. The Intelligent Systems Integration Program, an initiative of the Department of Trade and Industry and of the Engineering and Physical Sciences Research Council, is aimed at developing and integrating intelligent systems technologies into the U.K. business sector. The U.K. has a wide range of academic research and professional organizations related to intelligent systems:

- The Center for Intelligent Systems at the University of Wales, Aberystwyth, is developing AI and sensing techniques for the manufacturing industry. Research covers model-based reasoning for design and diagnosis, intelligent software for failure mode and effects analysis, intelligent instrumentation, and intelligent automation.
- The Intelligent Systems Laboratory in the Department of Computing and Electrical Engineering, Heriot–Watt University, is working on a combination of AI logic with control engineering methods to produce intelligent systems for engineering applications. It is the source of the Model-Based Intelligent Training as well as a partner in a number of ESPRIT projects.
- The University of Essex Computer Science Department has been prominent in AI education and research since the early 1970s. Topics include natural language processing, autonomous agents and robotics, intelligent autonomous systems, fuzzy control systems, genetic algorithms, machine learning, machine vision, and neural networks.
- Researchers at the University of Cambridge and the Sheffield Speech and Hearing Research Labs are developing a hybrid-neural-network/ Hidden Markov Model-based automatic speech recognition system.

- The Edinburgh University Department of AI specializes in natural language processing, mobile robotics, and computer vision systems through its Machine Vision Unit (MVU). MVU projects of note include LAIRD (see below).
- Location and Inspection With Range Data (LAIRD) is a consortium of companies and universities led by British Aerospace and funded by the U.K. Science and Engineering Research Council (SERC). Its aim is the investigation of 3D machine-vision techniques and their applicability in industrial environments. A recent project involves acquiring 3D models automatically from multiple range data. The project is sponsored by SERC (Applications of Computers to Manufacturing Engineering Directorate), with MVU as the main investigator. Industrial collaborators are British Aerospace and the National Advanced Robotic Research Center, Salford.
- Advanced Robotics Research Ltd. is a joint U.K. government–U.K. industries-funded research organization involved in the research of enabling technologies for advanced robotics systems.
- The Electronics Research Group of the University of Aberdeen in Scotland is notable for the range of applied neural logic research.

French research into intelligent systems has heavy governmental support. Some basic research is through the French CNRS. The most prominent CNRS research has been through R&D groups and coordinating research programs in communications man–machine and artificial intelligence. Two of the most important centers for these efforts have been the Laboratory of System Analysis and Architecture and the Laboratory of Computer Science, Robotics, and Microelectronics. However, the bulk of advanced research is done through the five regional institutes of the INRIA.

Research in intelligent agents is being pursued by organizations associated with simulation and communications. Principally these are the Laboratory of Computer Science and AI of the Computer Science and Applied Mathematics Institute of Grenoble, Dassault, and the R&D Center of France Telecom.

Thomson–CSF is the principal developer of the EC-sponsored work in VR databases. In the realm of dynamic simulation and training, the French have developed capabilities in multi-expert and split systems (which allow presentation of synthesized or split data), HCIs, and speech recognition. Thomson–CSF has also been working to develop neural networks for use in automatic target recognition, scene analysis, signal and image processing, process control, and data fusion. A joint program with the U.K. has augmented French capabilities in real-time automated feature extraction. The French also have niche capabilities in neural logic and fuzzy logic, principally in the area of fuzzy-neural (soft computing) hybrids. Some limited work in genetic algorithms has been reported related to intelligent agents.

The major source of German government-sponsored academic intelligent systems research is through the German AI Research Center (DFKI) of the GMD. Major efforts at the research center include multi-intelligent agent systems, HCIs, knowledge validation and exploration, intelligent engineering, constraint-based programming, and multilanguage automated speech recognition. Germany has a continuing interest in developing intelligent industrial robotic manufacturing capabilities. They also have significant capabilities in machine vision, which is currently being applied to the EUREKA-sponsored Prometheus unmanned vehicle navigation program. Researchers at the Institute for Microelectronics Stuttgart are looking into building fault tolerance into neural networks. Siemens has successfully used neural logic for engine failure prediction of large induction motors and is developing a neural network system for industrial scene analysis. They are also pursuing research into genetic algorithms.

The primary R&D organization for the Netherlands is TNO. Intelligent systems research is focused on the following:

- *Perception*—Vision and imaging systems, primarily in object recognition and target detection, image analysis, visual search, image fusion, and VR. This includes visualization, speech recognition, speech synthesis, voice control, and quality testing of communication channels. Other capabilities include directional hearing, virtual acoustics, audiometry, and noise avoidance.
- *Information Processing*—Cognitive skills, decisionmaking, decision support system, C^2 systems, and knowledge acquisition. HCIs include dialog, user interfaces, quality of information transfer, and operator behavior monitoring.

SWEDEN RESEARCH GROUPS

***Knowledge Technology and Methodology Group*—Planning, scheduling, and software integration**

***SICS, Intelligent Systems Laboratory*—Agents and secure computing and distributed decision support**

***SICS, Neural Networks and Real-Time Computation Group*—Consists of two RWCs and one non-RWC laboratory. The projects sponsored by each laboratory aim at better understanding of the mechanisms used by natural and AI systems, such as humans, animals, robots, and other autonomous intelligent agents**

***SICS, Distributed Collaborative Environments Group*—Active in the area of distributed VR systems, it has developed a generic VRI, distributed interactive virtual environment, which is used as a research platform for studies into remote teleoperation, battlefield simulation, multimodal integration, and conferencing**

***Department of Computer and Information Science, Linkoping University*—laboratories devoted to intelligent systems R&D, including labs dedicated to NLP and speech recognition (fairly mature), real-time systems (the most well developed), and autonomous systems**

***Goteborg University*—with the largest corpus of Swedish governmental text to support statistical analyses for development of machine translation/NLP**

The primary organizations for defense-related R&D in Sweden are the National Defense Research Establishment, Swedish Defense Materiel Administration, Swedish National Board for Industrial and Technical Development, and Swedish Institute of Computer Science (SICS). SICS appears to be the foremost national R&D organization dedicated to the development of advanced capabilities in intelligent systems technologies. SICS is a nonprofit research foundation funded by the Swedish National Board for Technical and Industrial Development and by a group of companies (Ericsson, Celsius, etc.).

Canada is actively partnering with industry and academia in intelligent systems research, largely accomplished with minimal federal government funding. Basic research is being pursued by the Canadian Institute for Advanced Research. Advanced intelligent systems research is being done by PRECARN Associates Inc., a nonprofit organization representing a consortium of private industries, and through the Institute for Robotics and Intelligent Systems, a government-funded, university-based "Network of Centers of Excellence."

Another notable intelligent systems R&D organization is the Intelligent Machines and Manufacturing Research Center at McMaster University (Hamilton, Ontario). The center was established in 1992 to provide a high-profile vehicle for university-industry-government research into intelligent machines and manufacturing. There is also an active participation of the Montreal-based Computer Science Research Center and Environment Research Institute (ERCIM) with French intelligent systems R&D projects. The Canada's Nortel has an active partnership with the German firm DASA to develop capabilities in telephony-based automatic speech recognition.

One of the effects of increased computer hardware performance and communications bandwidth has been to spur rapid interest and growth in VR. Although the United States holds or shares a lead in most areas of HCI research, the U.K., which has an existing cooperative effort in HMDs with the Air Force and NASA Ames, France (visually coupled displays and digital scene generation), Canada (head-mounted stereo displays and large dataset visualization), Germany (applications to robotics and teleoperations), and Japan (visually coupled systems) have world-leading development efforts. Other countries have niches of capability, two notable examples

being the strong capability in haptic devices at the University of Pisa in Italy and Israel's work in heads-up displays.

There have been many projects sponsored by the EC for development of capabilities in systems technologies. Some of the most notable are the Falcon, which focused on developing fuzzy logic intelligent process control systems, and Wernicke, which focused research on the development of neural-logic-enabled speech recognition. In the rapidly developing area of VR, ESPRIT has established a working group called Framework for Immersive Virtual Environments. Their goals involve reducing latency of image generation, multimodal integration, tracking technology, modeling of participants, and simulation of virtual humans.

EC-SPONSORED ORGANIZATIONS WITH SYSTEM TECHNOLOGY CAPABILITIES

ECVNET—The network (started in 1994) dedicated to the development of capabilities in computer vision. Overall objectives include improved capabilities in movement control, image understanding, and HCI interfaces

ELSNET—The network of excellence dedicated to R&D of speech and natural language processing technologies. The multinational environment of the EC has prompted an active, long-term (since 1991) effort in this area

ICIMS—A network of excellence focused on integrating intelligent process control into manufacturing systems

b *Command, Control, and Communications*

As delineated in the *Joint Warfighting Science and Technology Plan,* the goal of C^3 is the seamless and effective integration of capabilities for planning and preemption and integrated force management. In addition, the Army C^4I technical architecture indicates that digitization of the battlefield is expected to rely largely on the effective use of COTS equipment.

C^3 technology encompasses the capability to acquire, process, and disseminate information across force elements (including international coalition forces). This capability must be reliable, provide secure multilevel access, and be protected from enemy attacks and eavesdropping. This will require advances not only in computing hardware and software, but in the interconnecting fabric of communications.

Technical challenges exist and include developing an environmental and force structure database and reasoning mechanisms that are scalable, dynamic, extensible, and robust. In addition, the system must be affordable and offer real-time response. The decision-aiding and -planning aspects require improved machine learning and reasoning paradigms coupled with intelligent agents or aids. Decision aiding also requires a useful human–computer interface, since each decisionmaker has a uniquely preferred manner for quickly absorbing information on which to make a decision. Decision aiding should be available to Army users with the capability to have the decisions made automatically if the user chooses to operate in that mode.

A number of international cooperative opportunities support Defense Technology Objectives; this will help to achieve information superiority and operational dominance in the battlespace of the future. The breadth, diversity, and number of the areas highlighted in this subsection reflect the nature of the global information infrastructure. Areas where existing or pending agreements offer significant opportunities for cooperation are noted.

The United States leads the world in systems engineering and integration of complex C^4I systems. Areas where international developments are likely to provide cooperative opportunities include:

- High-speed digital switching and networking techniques supporting seamless communications and robust interoperable systems.
- Machine translation software products and intelligent agents for data acquisition and retrieval.
- Intelligent systems technologies for real-time decision support.

The U.K.'s University of Edinburgh's Department of AI is conducting technical research in the areas of knowledge and information management and task and process management. Japan offers world-class capabilities in high-speed switching and networks that could be a valuable contribution to this area.

France, Germany, and the U.K. have significant capabilities in information management and distribution. In addition, Canada has strong capabilities in advanced data display. Another NATO country with noteworthy capabilities is the Netherlands, which has particular strengths in knowledge base and database science. Canada has significant ongoing efforts relative to data fusion and the underlying technology applied to military intelligence. Cooperative efforts with these countries would be beneficial in applying state-of-the-art technologies to address the data fusion problem. The following are examples of potential cooperative opportunities:

- *Real-Time Distributed AI-Based Data Fusion*—Applications of distributed intelligent systems to real-time data fusion and combat battle management. The objective is to incorporate AI into large, synthetic computing environments to handle networking and process management automatically and transparently for the network user. France has extensive experience and a sound information technology infrastructure combined with strong capabilities in battlefield communications.
- *Next-Generation Tactical Switches*—To increase information flow to and from the land forces (Army) commander. Advanced asynchronous transfer mode (ATM) switching promises many advantages to the next-generation information infrastructure for commercial as well as military tactical and strategic applications. ATM allows one to dynamically allocate bandwidth for a fixed packet (information fragments) size. Coupled with switching, packets are individually routed to their destination: a direct communication path is not set up. In other words, in a single message, individual packets can take different paths to get to their destination. France has significant capabilities in this area of technology.
- *Machine Translation*—For information exchange between U.S. and allied forces in a combined operation. Military communications offer a promising area for implementation of machine translation because of the relatively limited and specialized military lexicon. Two areas are of special interest, one with Germany and one with France. The German army has developed a prototype translation system consisting of a 16-channel recorder, a server, two workstations, and an electronic military lexicon. The German army is interested in further development of this capability in the areas of language and speaker identification. World-class research in machine translation is being done in Germany at Siemens and the University of Karlsruhe. A French–English interlingual-based machine translation system, capable of high-quality translation of complex sentences in the domain of military free-text messages, is being developed under a 4-year effort between France and the United States. Using corpus material from U.S. Army CECOM, the system will contain semantic lexicons of both French and English, each having 1,000–3,000 root word form entries, graphical user interface tools, and wide-coverage grammar parsers and generators.

1) Human–Computer Interface

The Swedish foundation SICS has a center for HCI and language engineering doing work in spoken language systems (speech recognition and natural language processing).

The impact of available computing power has had a significant impact on the development and proliferation of HCI technologies. One example is the Laboratory of Computer Science for

Mechanical and Engineering Sciences of the French CNRS. In this institute, the growing use of computers as a tool for research led to the development of a separate department for HCI. Apart from the absence of haptics, the topics covered represent a good representative view of HCI research of interest to the Army:

- *Spoken Language Processing*—Analysis, synthesis, and perception; acoustic and lexical modeling; linguistic modeling; and recognition/understanding.
- *Language and Cognition*—Architecture and semantic representation, learning, spatial and temporal reasoning, testing, and written dialog.
- *Multimodal Interaction*—Computer vision, gesture analysis and synthesis, multimodal communication, audio scene analysis, and ergonomics and human factors.

2) Seamless Communications

Seamless communication means robust, survivable, multilevel, secure communication systems that provide the warfighter access to mission-essential information over the entire operational continuum without requiring user intervention to achieve connectivity across heterogeneous networks. Seamless communication includes the technologies associated with networks, network management, and advanced radio communication systems. The technical challenge is to provide local area networks and ground mobile radio networks that will survive the hostile and demanding environment of the modern battle and that are capable of being interfaced to fixed backbone or space-based wide area networks. France, Germany, and the U.K. are major players in all aspects of communication networks and in battlefield interoperability. Canada also has significant capabilities in tactical interoperability. The following programs are of particular interest for cooperative opportunities:

- *Battlespace C^2*—Seamless information transfer in C^2 to include collaborative planning, intelligence, logistics, and weather. France, Germany, and the U.K. have significant capabilities and ongoing cooperative relationships with the United States to develop joint C^2 capabilities. There is a need to address and expand this effort to effect force compatibility with Republic of Korea (ROK) forces where the U.S. Army has a large, ongoing commitment. ROK is far behind in implementing and fielding below-division C^2 systems.
- *Command Post Communications*—Broadband communication networks for corps, division, and brigade command posts. Germany is developing a wideband, wireless command post communication network that will provide voice, digital data, and video connectivity among the elements of a dispersed command post. This system is similar to that being investigated in the U.S. Army's Survivable Adaptive System ATD. There is potential for data exchanges and an interoperability effort between these two programs. A key German technology includes ultrafast (40 GHz) optical switching developed by the Heinrich Hertz Institute.
- *Battlefield Interoperability*—Implementation, evaluation, and validation of improved interoperability between the tactical (regiments, battalions, and companies) C^2 systems of different allied nations. One area of interest involves developing an intelligent translation gateway box that receives variable message formats from a command post in English and converts them in real time to French common AdatP3 message format and vice versa. A similar effort with Germany is ongoing as a follow-on to an MOU related to the combat vehicle C^2 system. Successful field experiments conducted in November 1997 demonstrate the feasibility of these concepts.
- *International C^2 Systems Interoperability*—An Army strategy for international digitization. A joint testbed facility would be established to conduct R&D that demonstrates and evaluates interoperability and implements new procedures and functions required for a digitized battlefield. Initial efforts involve Germany, but this testbed should accommodate joint testing between U.S. and other multinational forces. Success of battlefield interoperability field tests resulted in continued joint activities under the Army Tactical Command and Control System program.

- *Tactical-Level Allied/Coalition Force C^2 Simulation*—Providing a tactical-level C^2 exercise for a U.S.–French allied task force utilizing distributed interactive simulation protocols in a Janus environment. This effort will begin to evolve a plausible doctrine, tactics, and training procedure with the concomitant military language, symbology, and rank structure. It will also provide the architecture for integration of military equipment and systems to form a unified C^2 structure where this is politically acceptable.

Information Management Assurance and Distribution. Information management and distribution provide accurate, real-time knowledge of the enemy and the ability to automatically disseminate that information to dispersed forces and command centers. Technical challenges relate to heterogeneous, distributed computing environments; distributed database management; multilevel information security; advanced HCIs; and automated information distribution. In addition, technical challenges exist for both the commercial world and the Army in the areas of information security and assured routing and access.

3) Decisionmaking

Decisionmaking or battle command remains a combination of art and science. The nonhierarchical dissemination of intelligence, targeting, and other data—facilitated by seamless communications and effective information management—will replace the current hierarchical command structure. Essentially, units, decisionmakers, and commanders will be more independent and dispersed. Information will be voluminous, asynchronous, ambiguous, partial, and at times erroneous. Two conclusions may be drawn:

- To support this revolution in battle command, dispersed command units must be able to share a common, accurate picture of the battlespace.
- To take advantage of information, a multilayered reasoning environment is required to aid the warfighter and commanders in making battlefield decisions. This includes the use of fuzzy logic—which replaces Boolean logic by allowing partial truths rather than *completely* true or false solutions.

France and the U.K. have special capabilities in the area of fuzzy logic technology that offer opportunities for potential cooperative efforts. The French are doing world-class research on automated mission planning and decisionmaking systems. This requires evaluation of potential paths based on a perception of the current true situation. In virtually every case, this is populated by vague or uncertain data (e.g., data on enemy positions, weapon ranges, reaction time, efficiency). Conventional rule-based approaches do not work well with such data. Fuzzy logic approaches for data collection, aggregation, and potential dissemination are being integrated into an automated system to allow manipulation of vague data to increase realism of simulation and ultimately of decisionmaking.

The U.K. effort is focused on the potential payoff from incorporating fuzzy logic techniques into a large-scale battlefield decisionmaking simulation. Intelligent command aids could be extremely important in simulation and computer-generated forces (CGF). A common problem is that it is far too expensive to have human controllers "command" the CGF. Rather than using large, rule-based systems to construct "command agents" (which attempt to model individual decisionmaking entities), fuzzy logic and fuzzy inference engines are an approach that can enhance current intelligent command aids and provide more realistic and effective simulations. The conventional, rule-based implementation system designed to simulate battlefield decisionmaking (GeKnoFlexE) was developed by the U.K. (Fort Halstead) and will be the testbed system. The current rule-based inference structure will be "fuzzified" by augmenting or replacing

it with fuzzy rules and fuzzy inference mechanisms. Since the current system is nonfuzzy, direct comparisons of complexity, behavior, and other performance parameters will be possible.

Israel has strong capabilities in automated battle management that could offer an important contribution to this effort. Japan also has significant capabilities in the application of fuzzy logic techniques. Most Japanese work is related to control of industrial processes or consumer products; however, it is also applicable to military decisionmaking and mission planning.

c *Modeling and Simulation*

M&S objectives, as defined for this technology area, include development of a common technical framework for M&S; timely and authoritative representations of the natural environment (e.g., friend, foe, and human behavior systems); and development of an M&S infrastructure to meet developer and end-user needs. These areas are critical for achieving the JCS vision for the integration of mission planning, rehearsal, and execution—the application of which should be carried out with overwhelming force.

DMSO is leading a DoD-wide effort to establish a common technical framework to facilitate the interoperability of all types of models and simulations among C^4I systems. This framework includes the high-level architecture and represents the highest priority effort within the DoD M&S community. HLA was approved as the standard technical architecture for all DoD simulations in September 1996.

The primary mission of HLA is to define a consistent and common picture of the battlespace. This will be crucial to the effective employment and interoperability of multinational coalition forces. HLA will define an infrastructure for linking various highly complex simulations at multiple locations to create realistic virtual worlds. Further international cooperation will be essential. These exercises are intended to support a mixture of virtual, live, and constructive simulation. HLA will identify the interface standards, information structures and exchange mechanisms, and other data required to transform heterogeneous simulations into a cohesive, synthetic environment. Such environments will support design and prototyping, education and training, test and evaluation, emergency preparedness and contingency response, and readiness and warfighting.

The growing cost of hardware development and testing in virtually every product area—coupled with the worldwide availability of low-cost computing power—has made M&S a major area of research worldwide. The International Society for Computer Simulation boasts worldwide participation and has established a "virtual" institute: the McLeod Institute of Simulation Sciences. Its purpose is to promote the advancement and dissemination of M&S technology. International institute members include University of Calgary; Laurentian University; University of Ottawa (Canada); Italian National Research Center; University of Ghent (Belgium); Polish Academy of Sciences; University of Edinburgh (Scotland); Universidad Panamericana (Mexico); Beijing University of Aeronautics and Astronautics (China); Riga Technical University (Latvia); Hungarian Academy of Sciences; Technical University of Clausthal (Germany); and De Montfort University (U.K.).

1) Simulation Interconnection

Simulation interconnection is concerned with the international development of HLA. Such requirements include development of an advanced run-time infrastructure (RTI) (time, data distribution, and large-scale federation management); development of automated tools to support

federation development; investigation of innovative techniques for supporting scalable executing systems using HLA; and development of an automated HLA compliance testing capability.

Technical challenges include establishing the architectural design, protocols and standards, and security mechanisms to facilitate the interoperability of simulations; developing the supporting infrastructure software to apply the architecture to simulation applications with the needed levels of performance; and extension of the architecture to provide time management, data distribution, and federation management services.

In addition to Canada, the U.K., Australia, and New Zealand (all of whom participate with the United States in TTCP), France, Germany, and the Netherlands have strong capabilities in M&S and in the underlying information systems technologies required to distribute and process the information. Japan has had an extensive M&S program aimed at management of large, complex, distributed enterprises. Other capabilities, including those of Israel, may also contribute.

The United States is a world leader in this area. HLA and RTI have emerged and are becoming widely accepted as de facto standards for distributed simulation by the international community.

Examples of global research in development and application of HLA include work at the Interactive Information Institute, Royal Melbourne Institute of Technology, a cross-faculty institute that is becoming a major base for simulation technology research in Australia. The Distributed Knowledge Processing Group at the University of Surrey is also actively pursuing techniques for distributed simulation. The University of Magdeburg, University of Hamburg, and German National Research Center for Information Technology are also active in this area.

2) Simulation Interfaces

This subarea addresses modeling of mission space, mission tasks, strategy, tactics, intelligent systems emulating human decisionmaking processes, and optimal resource utilization. To achieve this ability, it is necessary to develop simulations that provide consistent and reliable results through the development of common conceptual models of the mission space using authoritative representations. Common syntax and semantics must be developed to specify the warfighter mission (the entities, their actions and interactions) to the simulation developer; and to formulate and define standard data structures, dictionaries, and enumeration of complex M&S data (e.g., highly derived data, command hierarchies, artifacts of legacy systems). Areas of interest include the development of an M&S resource repository and verification, validation, and accreditation/certification standards and guidelines.

Several factors are fostering rapid growth of simulation information and representation. Coalition operations are a major theme in the use of military force. The threat to these forces, geographically dispersed and increasingly capable technologically, demands more effective transnational mission planning and rehearsal. The same requirements and capabilities are, to only a slightly lesser extent, reflected in the operations of large multinational companies. Worldwide availability of low-cost, powerful information management systems are allowing exchange of data and promoting standardization of data and models for terrain, weather, and environmental effects. The resulting advances will contribute directly to improved interoperability of coalition forces.

The challenge to developing coherent, complete, and consistent conceptual models of the mission space is an extensive task. The span of military M&S covers a wide range of missions, from conventional to other-than-war missions and M&S applications, and from systems acquisition activities to mission planning and rehearsal. The distributed and interactive nature of advanced M&S capability and security concerns makes the standardization and ready availability of standardized data an extremely complex technical issue.

3) Simulation Information

The simulation information subarea is concerned with technologies that will enable—within the time of operational decision cycles—the generation of realistic and high-fidelity synthetic representation of the prevailing physical environment (natural and manmade), the natural and human elements operating within it, and their interactions with each other. These technologies will enable developers and users of M&S applications to represent the natural environment, the performance and capabilities of warfighting systems, and human behaviors (individual and group) in a manner that promotes cost effectiveness, ready access, interoperability, reuse, and confidence. This will enhance the realism of models and simulations used in military training, acquisition, and analysis by providing authoritative representation for (1) static and dynamic, natural and manmade environments, and related effects on human and system performance; (2) the performance and capabilities of warfighting systems and their effects on natural and manmade environments; and (3) human behavior (individual and group).

Technical challenges include rapid database generation and near-real-time interaction of consistent and correlated representations. The representation of human behavior must reflect the effects of the capabilities, limitations, and conditions that influence human behavior (e.g., morale, stress, fatigue). Another significant challenge will be to provide variable human behavior for friendly, enemy, and nonhostile forces, to include CGFs that exhibit platform-based behavioral modeling and command forces models through division level.

The United States has the largest body of research directed toward Computer-Generated Actors (CGAs) for military M&S. However, modeling of human behavior is an area of widespread academic research. Much of this work is focused on meeting the objectives of the synthetic theater of war. Key players in the area of CGAs in the United States include the NASA Virtual Environment Technology Laboratory, University of Houston; the U.S. Army Simulation, Training, and Instrumentation Command; and related work at the University of Central Florida, which is a recognized center of excellence for M&S.

The Advanced Distributed Simulation Research Consortium, consisting of Grambling State University, Florida A&M University, University of Houston, and University of Central Florida, conducts research in application of parallel and distributed evaluation, visualization, and AI reasoning to advanced DIS.

Human behavior modeling programs are conducted at the European Institute of Cognitive Sciences and Engineering in Toulouse, France; the University of Amsterdam, the Netherlands; and the School of Computer Science, University of Birmingham (U.K.) Cognitive Science Research Centre.

The objective of the University of Cambridge (U.K.) Cognition and Emotion program is to develop a theoretical understanding of the nature of emotion and of the cognitive (e.g., attention, interpretation, memory) and brain processes that support normal emotional behavior and

response, as well as emotional disorders. The Geneva Emotion Research Group is part of the Faculty of Psychology and Education Sciences at the University of Geneva, and it conducts research on emotions, including experimental studies on emotion antecedent appraisal, emotion induction, physiological reactions, and emotional behavior in autonomous agents. Although this work is primarily directed toward modeling and understanding of individual and group interactions in civilian settings, the underlying data and techniques should be transferable to military scenarios.

4) Simulation Representation

The simulation representation subarea addresses interfaces required for seamless integration of models and simulations with "live" systems, which may consist of instrumented individuals or platforms used for training, testing, or other synthetic environment applications. Interactions with C^4I systems and simulations are a priority. Common operational planning and simulation tools and the development of a modular reconfigurable C^4I interface will focus on these interfaces. This critical capability will facilitate the use of M&S in providing mission rehearsal capability and could augment existing operational planning processes and systems.

SIMULATION TECHNICAL CHALLENGES
Modular interfaces that are (1) responsive and easily reconfigurable for multiple similar but heterogeneous systems, and (2) compliant with Joint Technical Architecture and the M&S common technical framework
Accurate representation of live systems and individuals in a simulation
Realistic representation of synthetic forces on tactical systems

In the subarea of simulator interfaces, leading technologies are found primarily in those countries that have been traditionally strong in dynamic training and simulation—Canada (which is also developing significant capabilities in data visualization), the U.K., France, Germany, and Japan (which is actively pursuing the development of VR for industrial applications, including visualization of complex systems and enterprises).

d *Example Research Facilities*

The following facilities have demonstrated expertise in C^4 technical development:

- Canada—Carleton University, Ottawa, Network Management and Artificial Intelligence Laboratory [http://www.carleton.ca]
- European—Canadian Consortium, DASA, and Nortel [http://www.bdli.de/english/katalog/daimle5a.htm]
- Japan—The RWC Program [http://www.rwcp.or.jp]
- Greece—Athens High-Performance Computing Laboratory; Zentren Europaischen Supercomputings Centers of European Supercomputing [http://www.iwr.uni–heidelberg.de/zeus].

3 Electronic Warfare

Because research in the Electronic Warfare area may require sharing of sensitive threat information and is handled on a case-by-case basis, no technology development tabulation can be shown.

a *Electronic Area and Self-Protection*

Electronic self-protection includes actions taken to protect personnel, facilities, or equipment against EW that might degrade, neutralize, or destroy combat capability. Sensor and countermeasures technologies are essential elements in the complex battle that pits defensive EW systems against the enemy's offensive systems. On the modern battlefield, this is an encounter in which a timespan of 1 or 2 seconds can mean the difference between winning or losing. Advanced technology is critical in providing the winning edge in performance. Technical goals include development of multifunction and multispectral IR countermeasures, radar and laser warning, and real-time situational awareness. Technology challenges include development of uncooled, low false-alarm rate detectors, multicolor IR FPAs, missile detection algorithms, and more efficient, low-cost, and temperature-stable IR/UV filters. Development of high-speed wideband digital receivers based on gallium arsenide technologies will also play a key role in electronic protection, as will development of high-power, UWB jamming modulators and transmitters. This area may require sharing of sensitive threat information, system characteristics, and vulnerabilities. All cooperative efforts involving electronic self- and area protection must be handled on a case-by-case basis, and no technological areas of special interest are identified in this summary.

b *Electronic Support*

Electronic support includes actions taken to search, intercept, identify, and locate sources of radiated EM energy for threat recognition in support of EW operations and other tactical actions, such as threat avoidance, homing, and targeting. Technologies to intercept, direction-find, and locate current and emerging hostile emitters are critical for targeting and tactical situation awareness. Next-generation electronic support measures processors must offer improved emitter identification, deinterleaving techniques, direction-finding/geolocation algorithms, multipath suppression techniques, and increased capabilities in the super-high-frequency region. Continued development of correlation and templating, automated tracking, cross-cueing, and situation display tools are also important. Technical challenges include the integration of ceramic phase shifters into phased-array antennas, application-specific integrated circuits for fast Fourier transform processing, and tools and techniques for tasking and reporting from multi-intelligence sensor platforms. This area may require sharing of sensitive threat information, system characteristics, and vulnerabilities. All cooperative efforts involving electronic support must be handled on a case-by-case basis, and no technological areas of special interest are identified in this summary.

4 Ground Combat and Tactical Systems

Ground combat technologies support the basic Army and Marine Corps land combat functions: shoot, move, communicate, survive, and sustain. Rapid deployment, manageable logistics, and compatibility with Third World infrastructures are current topics of major interest. Specific objectives include advances in diesel and gas turbine propulsion, better track and suspension to increase cross-country mobility, and enhanced survivability through improved ballistic protection and reduced observables (including use of active armor). Table E–3 summarizes capabilities and opportunities in each technology subarea.

AMC POC

Dr. Rodney Smith
e-mail: rsmith@hqamc.army.mil

IPOC—Mobility

Mr. Stephen Cohn
e-mail: scohn@arl.army.mil

MSC IPOC—IVES, Mobility, Integrated Survivability, & Vehicle Chassis & Turret

Mr. William Lowe
e-mail: lowee@cc.tacom.army.mil

TABLE E–3. TECHNOLOGY DEVELOPMENT—GROUND COMBAT AND TACTICAL SYSTEMS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
SYSTEMS INTEGRATION						
♦♦♦♦ EC nations have capabilities in various areas		♦♦♦♦+	*Japan* ♦♦	♦♦♦♦	♦♦♦	*Israel* ♦♦♦♦+ RPVs Teleoperation *Switzerland* ♦♦♦♦ Armored vehicles
CHASSIS & TURRET STRUCTURES						
♦♦♦♦	♦♦♦♦	♦♦♦♦ Structure & design	*Japan, China, ROK* ♦♦	♦♦♦♦		*Israel, Sweden, Switzerland, Italy* ♦♦♦♦
INTEGRATED SURVIVABILITY						
♦♦	♦♦ Modular armor	♦♦♦♦+ Vehicle survivability		♦♦ Bulk ceramics Active protection		*Israel, Sweden, South Africa* ♦♦
MOBILITY						
♦♦♦♦+ Gas turbines ♦♦♦♦ Power conversion	♦♦♦♦+ Secondary batteries	♦♦♦♦+ Autonomous control Diesel engines electric drive	*Japan* ♦♦♦♦+ Ceramic engine Electric drive	♦♦♦♦ Electric drive components, batteries & switches	♦♦♦ Suspensions	*Austria, Ukraine* ♦♦♦ Diesel engines
VEHICLE ELECTRONICS						
♦♦♦♦	♦♦♦♦ Multisensor integration	♦♦♦♦+ Integrated electronics & optronics	*Japan* ♦♦♦♦ Displays			

Note: See page E–6 for legend.

a *Systems Integration*

Each ground vehicle consists of several subsystems (e.g., power and drive train, electronics, weapons, sensors) that must be integrated into a full-up, system-level technology demonstration. The primary process in the design of future vehicles is virtual prototyping. Modeling and simulation (M&S) will develop preliminary concepts, optimize design, reduce cost, and schedule maximized force effectiveness for ground vehicles. The goal is to develop lighter, more lethal, and more survivable ground vehicles that are crewed by fewer people. Virtual concepts can be readily evaluated for mobility, agility, survivability, lethality, and transportability, forming a basis for validation, verification, and accreditation. The major technical challenge is to provide the user with systems that can attain an effective balance between increased fighting capability, enhanced survivability, and improved deployability, while meeting cost, manufacturing, and reliability/maintainability goals. Specific challenges relate to developing verifiable models within a usable time frame.

The major players in ground vehicle systems integration and design are the U.K., France, Germany, Israel, Japan, and Russia, all of which have a long history of developing and manufacturing military armored systems, including main battle tanks. Switzerland also has substantial capability in armored vehicles that may be of interest, and Israel has unique experience in the use of RPVs and UAVs that may contribute to advances in teleoperation of ground vehicles.

b *Chassis and Turret Structures*

Use of composites and titanium alloy materials will result in future combat vehicles that are lighter, more easily deployed, economical, and survivable. These technologies remain key to optimizing and exploiting structural integrity, durability, ballistic protection, repairability, and signature reduction. Future vehicle chassis and turret assemblies will be fabricated through an integration of advanced designs that include combinations of lightweight structures and modular armor packages.

Using composite materials and titanium for the primary structure of a combat vehicle is a new effort. This will present significant technical challenges. Issues related to composite materials include durability, fabrication, producibility, and repairability. The primary concern for titanium is one of relatively high cost, which so far has kept it from being used in any U.S. ground combat vehicle. Advantages of titanium's potential for weight reduction, structural armor effectiveness, and corrosion resistance may overcome that cost concern.

The U.K., France, Germany, Israel, Japan, Switzerland, Italy, and Russia possess strong capabilities in vehicle chassis and turret technologies. Germany continues to be one of the few world leaders in combat vehicle R&D across all weight classes. Germany develops and fields wheeled combat vehicles that meet or exceed contemporary tracked vehicle standards and capabilities. DASA's design and prototyping have provided the basis for a German–French cooperative effort in medium-weight armored vehicles (Gepanzertes Transport Kraftfahrzeug), and their main battle tank development and prototyping continues beyond the Leopard 2 block improvements. In addition, the Embedded Gunner Simulator heavy combat vehicle technology demonstrator, developed by Krauss Maffei with firms such as Pietsch and Diehl and a host of others, incorporates state-of-the-art construction and materials fabrication technology with a special focus on signature management. Some capability in chassis and turret structures is noted in China and South Korea.

c *Integrated Survivability*

The goal of integrated survivability is to protect ground vehicles from a proliferation of advanced threats. Hit avoidance, detection avoidance, penetration avoidance, and damage-reduction technologies are critical to achieving overall vehicle survivability. Hit avoidance technologies confuse or physically affect incoming threats. Electronic countermeasures and improved sensors are key elements. Detection avoidance revolves around management of visual, thermal, radar, acoustic, seismic, and dust signatures. Armor is the major element in penetration avoidance. Damage reduction deals with flame suppression technology and fire-fighting agents and with compartmentalization of ammunition and fuel system vulnerabilities. Advances in penetration avoidance center on producing efficient armor combinations with reduced weight, space, and cost properties. The United States is currently the world leader, but other nations are improving rapidly. The Technical Cooperation Program (TTCP) nations have strong armor programs. Israel has strong capabilities, as evidenced by an indigenous development in the Merkava aimed at survivability. South Africa's Rooicat wheeled armored fighting vehicle incorporates a number of indigenously developed and integrated survivability features that include ballistic protection, obscurants, and collective CB protection.

The major technical challenge relates to the cost of the technologies required for survivability. In addition, many of the technologies have significant weight, volume, electrical power, and ther-

mal loading requirements that make their insertion into fielded systems both costly and time consuming.

The United States is the world leader in most aspects of integrated survivability, but niche capabilities may be found in countries that develop and manufacture armored systems. Germany has strong capabilities in integrated CBD and in indirect protection (detection and hit avoidance). The firm of Buck has conducted extensive research in multispectral obscurants. In direct protection, Deisenroth continues to be a leader in composite armor for light, medium, and heavy vehicles, both in integrated and modular add-on packages. Condat specializes in analytic and predictive modeling of armored systems vulnerability assessments. Russia has been a consistent world leader in active protection for 20 years. And Russian developments in bulk ceramics have potential for increased ballistic protection. Canada (Bosik) is noted for work on lightweight blast protection systems for vehicles.

Foreign military producers are undergoing mergers and acquisitions that cross many national boundaries and defense community identities. British Aerospace (U.K.), Marconi (Italy), and Alvis Vehicles and Hägglands Vehicles of Norway are examples. In addition, much of the current worldwide heavy armor industrial activity consists of upgrade and refurbishment of the older, existing inventory instead of new item manufacture. For example, Israel rehabilitates Chinese tracked vehicles, and the Czech Republic does the same for Middle Eastern national assets.

d *Mobility*

Mobility focuses on the "on-the-move" function of tracked and wheeled land combat vehicles. Mobility components include tracks, wheels, engine, transmissions, and their fuels and lubricants. Technologies of interest include active noise and vibration control to increase cross-country performance; quiet, lightweight band track; and advanced high-output diesel turbine engines and electric drives. Another major area of interest is providing increased electrical power in smaller, lighter packages. Electrical power is shared across the propulsion, survivability, lethality, and auxiliary systems. Management of distributed system energy requirements remains an important factor. Electric and hybrid drive systems are also being developed. To reduce operational and logistic support costs, the numbers and varieties of both fuels and lubricants required must be reduced through design and standardization.

Another key mobility technology is the development of advanced and active suspensions for enhanced cross-country performance of wheeled and tracked vehicles. Canada is noted for activity in the development of hydropneumatic suspensions.

Technical challenges for electric drives include power capability, energy storage, torque conversion, and reduction in the structural space required for the cooling system. For advanced track systems, the major challenge is to extend the lightweight conventional track durability while reducing O&S costs. For fuels and lubricants, the challenge is to define and select optimal performance tradeoffs for a single-engine/power-train lubricant.

In addition to the United States, Japan and Germany are the world leaders in automotive propulsion. Developments in both nations, in many cases, exceed those in the United States in the commercial arena. Germany is generally considered the leader in producing commercial diesel engines for the world marketplace. Japan and Germany both have significant capabilities in functional gradient coatings, monolithic ceramics, and standard engines and high-power-sensor

diesel engines. Much of this expertise is directly applicable to military vehicles. The U.K., France, and Ukraine all produce high-density combat vehicle diesel engines that are highly competitive. Austria is noted for expertise in diesel engines as well.

Interest in electric drives is found in the major automobile-producing and -exporting countries (U.S., Japan, and Germany), which is primarily driven by growing domestic restrictions on exhaust emissions. Japan is the world leader in some aspects of electric drive technology. France has special capabilities in secondary batteries, such as lithium (Li) polymer, which are of great interest for military applications because of their high energy and power density, long-life cycle, and rapid charge/discharge features. These are also lightweight, compact, and vibration resistant, and they have no EM signature. Military applications include electric vehicle (EV) propulsion (15 kW or more of power) and silent wake. The U.K., Japan, and Russia also have strong capabilities in Li battery technology. Another foreign capability of great interest is Germany's experience in hybrid EVs. Magnet Motors has been working in this area for over 10 years and excels in the areas of multiple electric permanent magnet motors and generators and in magnet dynamic storage. Other German firms—Siemens, Asea Brown–Boveri (ABB), Aus Erfahrung Gut, and Max Planck—are world leaders in microsystem technology as characterized by a combination of power semiconductors, which will make electric drives smaller, more robust, and more responsive. Russia has special expertise in certain types of very high-energy batteries and thermal batteries, and in certain silicon carbide (SiC) switching devices related to electric drives.

Another technology area of interest for mobility is that of autonomous navigation combined with topographic map or chart display and control of vehicles. Germany and the United States have a collaborative program entitled Next-Generation Autonomous Navigation (AUTONAV) System. Participating German research laboratories and their technological contributions to the project include:

- *Universitat der Bundeswehr Munchen* will produce an advanced autonomous road navigation system with cost-effective collision-avoidance technology. For a number of years, UBM has been a leader in the European Prometheus program oriented toward the development of commercial highway automation. As part of the Prometheus program, UBM has been developing a sophisticated highway lane-following system using only normal video technology for sensor input.
- *Dornier GmbH* will provide advanced off-road obstacle detection and avoidance capabilities using laser radar technology.

e *Vehicle Electronics*

The goal of the vehicle electronics effort is to develop a standardized framework within which to integrate digital technologies for embedded vehicular weapons systems. This goal is important for enabling current and future ground vehicles to maintain superior combat effectiveness in the digital battlefield. The two aspects to this area are (1) integration of the electronics into the vehicle, and (2) natural and seamless interconnection of smaller crews with the electronics. Installation of a standardized digital bus greatly simplifies later addition or replacement of electronic devices and will provide maintenance specialists with a single-point troubleshooting and fault-isolation capability for modules serviced by the digital bus.

TECHNICAL CHALLENGES: VEHICLE ELECTRONICS
Electronic integration techniques that are scalable to many platforms
Advanced crew station design
Near-real-time distribution of battlefield information within a vehicle
Reduction of system development time and cost
Reduction of system integration time and cost

PLANNED U.S.–GERMANY VEHICLE ELECTRONICS STUDIES
Day and night observation equipment
Sighting and fire control, including stabilized gun control systems
Data processing equipment, sensors, and modes logic
Radio and navigation equipment
Test, display, and operating equipment
Laser applications for battle tank fire control
Laser application for artillery fire control

The German firm Pietsch has conducted extensive crew compartment studies focusing on crew size reduction and human factors studies on topics including man–machine interface, endurance, and multiple or simultaneous tasking that results in stimulus overload. Integration of technologies such as sensor suites, optronics, and robotics has been demonstrated and continues to be pursued. Existing U.S.–German agreements are ongoing in support of efforts in this area.

Japan is the leader in commercial flat-panel display systems; however, the application, integration, and utilization of the technology to combat vehicle display systems is being accomplished to some degree in the U.K., France, and Germany.

f *Example Research Facilities*

The following facilities have demonstrated expertise in ground combat and tactical systems technology development:

- United Kingdom—Kidde Deugra GmbH, Kidde Graviner Ltd. [http://www.kidde–int.com/]
- Switzerland—International Center for Magnetic Bearings, National Research Institute for Metals [http://www.ifr.mavt.ethz.ch/research/icmb/index.html]
- Canada—DRES [http://www.crad.dnd.ca]
- Japan—NRIM [http://www.nrim.go.jp:8080/open/usr/harada/htm21–e.html]

5 Weapons

AMC POC

Dr. Rodney Smith
e-mail: rsmith@hqamc.army.mil

IPOC—Hypervelocity Propulsion

Mr. Dan Shumate
e-mail: dan.shumate–dl@rdec.redstone.army.mil

IPOC—Electronic Attack, Electronic Mission Support, & Electronic Self-Protection

Ms. Annette Chomsky
e-mail: annette.chomsky@mail1.monmouth.army.mil

Army goals in weapons technology include milestones for extending the range and lethality of conventional artillery and antiarmor rounds. Conventional weapons objectives are directed toward a variety of technologies for increasing the lethality and mission effectiveness of guided and unguided weapons and mines. Russia, France, Germany, and the U.K. are major developers of conventional weapons, followed closely in capability by Italy, Sweden, Canada, and Israel. Japan, which is prohibited by its national legislation from exporting weapons, has significant indigenous capabilities, as well as strong capabilities in certain lay component technologies such as gallium arsenide microwave components, neural net and fuzzy logic pattern recognition, and hypervelocity propulsion. Table E–4 summarizes international capabilities in the weapons technology area.

TABLE E–4. TECHNOLOGY DEVELOPMENT—WEAPONS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
GUIDANCE & CONTROL						
♦♦♦♦	♦♦♦♦	♦♦♦♦	*Japan* ♦♦♦ Components *Taiwan* ♦♦			*Israel, Sweden* ♦♦
GUNS—CONVENTIONAL & ELECTRIC						
♦♦♦♦+ ETC gun	♦♦♦♦	♦♦♦♦+ ETC gun	*Japan* ♦♦♦ Autoloading *ROK* ♦♦ Rail guns	♦♦♦♦ Pulsed power Autoloading	♦ Hypervelocity	*Israel* ♦♦♦♦ ETC gun *Australia* ♦♦ Rail guns
MISSILES						
♦♦♦♦	♦♦♦♦ ♦♦♦ Hypervelocity propulsion	♦♦♦♦ Vehicle integration Air-breathing rocket motors	*Japan* ♦♦♦ Hypervelocity propulsion Air-breathing rocket motors *India* ♦♦ SRBM & IRBM	♦♦♦♦		*Israel* ♦♦♦ BMD missile *Sweden, Switzerland* ♦♦
ORDNANCE						
♦♦♦♦ SAFF Energetic materials IM	♦♦♦♦ SAFF	♦♦♦♦	*Japan* ♦♦♦♦ Components *Taiwan* ♦♦		♦♦ Munitions	*Italy, Singapore, Brazil, India, Sweden, Switzerland* ♦♦
WEAPON LETHALITY & VULNERABILITY						
♦♦♦♦	♦♦♦♦	♦♦♦♦				
RADIO FREQUENCY & DIRECTED-ENERGY WEAPONS						
♦♦ HPM Coil, rail guns	♦♦ HPM		*Japan* ♦♦ ETC *ROK* ♦♦ Multisensor fusion	♦♦♦♦ HPM RF		

Note: See page E–6 for legend.

Armor and antiarmor technologies represent a special subset of operational capabilities toward which many of the subtechnology developments discussed below are directed. Technologies of interest include improved lethal mechanisms, advanced sensing techniques for optional delivery of the lethal mechanisms, and better methods of M&S of weapons effects and system vulnerabilities. Army objectives for improvements in tungsten alloy penetrators may be furthered by cooperation with other countries, including the U.K. and France. France has strong capabilities in explosives and propulsion systems, including air-breathing hypervelocity propulsion systems. Japan has also taken steps to improve its technological capabilities in aerospace materials

and aerodynamic design for hypersonic propulsion systems. Both of these could contribute to development of long-range hypervelocity systems for the Army.

a *Guidance and Control*

The United States has the largest and most varied inventory of terminally guided weapons and has pioneered virtually every major technological advance in this area. Other countries, however, have all demonstrated the capability to design and fabricate various types of terminally guided weapons. France (Crotale Air Defense, Air–Sol Moyenne Portee (ASMP) (air-to-surface), Magic (air-to-air), HOT, and trilaterial antitank guided weapon systems), Germany, Italy (Aspide, antiair missile), Russia, Sweden (Bofors) (look-down/shoot-down antiarmor system), and the U.K. all have designed and manufactured a variety of missile systems for a variety of mission functions.

Japan is a world leader in a number of component technologies (MEMS sensors, semiconductor and solid-state lasers, and IR detectors) used in small-body G&C, and the NAL has the expertise and facilities necessary for development of complete guidance subsystems. Also of related interest is NAL's ongoing research in hypersonic lift, which includes evaluation of aerothermodynamic effects and RF blackout. This, coupled with their superiority in fine ceramics, may provide an opportunity for cooperation in technologies that would ultimately lead to improved radomes for hypervelocity missile guidance.

Israel, South Africa, and Taiwan have indigenous capabilities for precision-guided weapons. A joint program with Israel involving their Arrow hit-to-kill tactical missile defense program is expected to go into limited operational use in the next few years.

Laser terminal homing is a critical area for advanced G&C. No other country is currently identified as having a program comparable to the Air Force's active laser terminal homing Low-Cost Autonomous Attack Submunition (LOCAAS) program. Among the specific areas of expertise where the United States leads are integration and optimization of guidance for maximum endgame lethality and thermal management and power distribution techniques for primary power. In this regard, use of a diode laser transmitter (as opposed to a diode-pumped, solid-state laser transmitter or master oscillator/amplifier configuration) reduces demand for primary electrical power (40–60 percent efficiency as opposed to 10 percent efficiency).

The United States enjoys a slim lead in the development of individual diode arrays and in laser-pumped and solid-state, diode-pumped laser sources. We also have a modest advantage in overall system design and integration by virtue of the extensive work done on a wide range of tactical, semiactive laser-homing systems. There are, however, areas of excellence abroad in supporting technologies.

Laser physics is a global endeavor with sound research being done in many different institutions. A number of countries have ongoing work in laser profiling and in laser-scale modeling of target radar cross section. The latter, while only peripherally related to full-scale target profiling, may provide useful insights into laser scattering characteristics at full scale. Similarly, a number of countries have strong capabilities in solid-state lasers. For example, in the area of components research, a large number of countries are active. Manufacturers of diode lasers are present in the United States, Canada, France, Germany, Japan, and the U.K. Other sources are identified in Israel and Switzerland. Other capabilities in this area are described in the following paragraphs.

A significant R&D effort in the area of CID is being done in Germany. The laser technology being pursued is of interest to the U.S. Army for possible use by dismounted soldiers. Siemens is a leader in developing algorithms for sensor fusion and high-speed processing, integration, and display of multisensor inputs. This has immediate application in situation awareness and could contribute to improvements in target detection and false-target discrimination techniques essential for laser terminal homing. The Fraunhofer Institut is recognized as a world leader in lasers and laser materials. The University of Frankfort (http://www.informatik.uni–frankfurt.de/~brause/welcome.eng.html] has a broad range of research in image analysis, and their Website provides useful links to related work. Other German activities include:

- Work at the University of Wurzburg in use of laser radar for localization and navigation. By contrast to existing industrial robots, the German work is directed toward landmark-independent navigation. Of note is the observation by German researchers characterizing the guidance methods as the technological bottleneck in this application.
- Research in a variety of algorithms for real-time image analysis at the University of Erlangen.
- Work in robust tracking methods for moving objects in high-noise environments.
- Work reported at the University of Hannover and the University of Harburg (the latter also working in collaboration with the Swiss Federal Institute of Technology).

Agreements with France in this technology area are in place under which potential cooperation in terminal laser homing might be explored. France is also working on an ATR algorithm running in real/near real time on a state-of-the-art processor. This is an integrated hardware/software effort currently directed toward forward-looking IR (FLIR) and radar sensing that might also be applicable to laser radar. The University of Lyons is active across a range of subtechnologies, including laser material and image analysis. Specifically in image analysis, the Center for Research and Applications in Image and Signal Processing [http://www.creatis.insa–lyon.fr/] is a joint effort of the CNRS National Institute for Applied Science of Lyons and the Claude Bernard University of Lyons, which consists of some 70 researchers dedicated to image engineering. The CNRS Ecole Polytechnique has also participated in international conferences on laser radar.

The U.K. has significant capabilities in laser technology and substantial efforts in radar and algorithm developments. The following are among centers of work and aspects of interest:

- University of Hull—work in optimization of algorithms for "zooming in" on images that support FLIR imaging systems.
- University of Nottingham—work primarily in real-time industrial applications of AI to image analysis.
- University of Bristol—efficient algorithms for texture analysis and classification.
- University of Cambridge—motion compensation techniques.

Japan has an active program in laser radar, much of which appears to be directed at atmospheric measurement and monitoring.

York University in Canada is a leader in laser radar technology. The main thrust of most of this effort appears to be directed toward atmospheric research, but some level of work and interest is in other aspects of laser radar. Optech

JAPANESE LASER RADAR FACILITIES

Tohoku Institute of Technology	Tohoku University
Fukui University	Yamagata University
Toshiba, Inc.	Chiba University
Mitsubishi, Inc.	University of Tokyo
NASDA	Fukuoka University
NIES	Nagoya University
The Japanese Defense Agency	Fukui University
Hitachi, Inc.	Okayama University
	Kyushu University
	Shinshu University

Inc., based in North York, Ontario, specializes in the use of laser rangefinder technology in a wide range of commercial applications. Three principal markets include airborne surveying, industrial process control, and locating/guidance applications for the transportation industry. Optech's activities include the manufacture of standard rangefinder products for established markets and the development of customized systems for new and developing applications.

Among the more radical approaches being investigated is a program at Australia's Aeronautical and Maritime Research Laboratory (one of two major laboratories in the DSTO), jointly funded by the U.S. Air Force, to investigate and develop insect vision-based algorithms for flight control and guidance of UAVs and missiles. Other countries having noteworthy work in related sub-technologies include Austria, Australia, China, Finland, Norway, and Sweden.

In addition to these individual research efforts, the European program for R&D in information technologies, ESPRIT, sponsors extensive research in image analysis. Projects under the ESPRIT program are multinational endeavors, frequently involving a mix of academic, government, and industry participation.

b *Guns—Conventional and Electric*

Advanced gun technology is an important component of the Army's R&D program. Weapons able to deliver effective payloads from longer range and with greater accuracy give a well-trained soldier a decisive advantage on the modern battlefield. Current propulsion technology is focused in three areas: advanced solid propellants, EM pulse (rail gun), and electrothermal-chemical (ETC) propulsion.

The United States currently has an active EM launch technology development program in cooperation with a strong program in the U.K. One of the outgrowths this joint program was the development of the world's longest free-flight EM gun test range at Kirkcudbright, Scotland. The facility has the capability of storing up to 32 MJ of energy and has a 2-km range.

The United States leads in the difficult challenge of developing an electric power generation unit capable of producing the required pulsed power within the confinements of a vehicle. The Netherlands and Germany have small-scale research in this area. South Korea is starting a development effort but has yet to develop a significant capability. Several countries are working toward integrating electric power units into vehicles.

In the area of gun propulsion, there are a number of opportunities in terms of new conventional propellants and technologies for ETC propulsion. In the longer term, advances in electrical pulse power may enable EM rail guns.

As discussed under the subtopic of insensitive munitions below, a number of countries are actively working on low-vulnerability ammunition (LOVA) propellants. The French–German Research Institute (ISL) has specifically studied the combustion behavior of hot-plasma-initiated LOVA propellant and related interior ballistics. The Australian DSTO is reported to be undertaking a comprehensive safety and suitability review of new high-performance nitramine propellants in both small- and large-caliber gun systems. Canada also appears to be doing some work in the area of hypervelocity projectiles, based on reference to a recovery technique developed by the DREV, that will allow recovery and post-flight analysis of aerothermodynamic effects for rounds up to 105 mm at 2,300 mps.

Among the most promising areas for future international cooperation are those associated with the development of pulsed power systems. Of interest, some of these are already being applied to other multinational initiatives. High-voltage/high-power semiconductor switches from ABB (based on technologies from Sweden and Switzerland) have been developed to support a French–German joint EM launcher program at ISL. These devices use a novel stacking and bonding technique to produce high-voltage, high-current stacks. In addition, a German–French consortium reportedly has been formed to exploit German capabilities in rotating machinery (specifically, German Magnet Motors GmbH.)

The Ioffe Technical Institute in St. Petersburg, Russia, has independently developed and successfully produced a new family of solid-state switches designed for high-frequency and pulsed-power applications. These are described by Army technical experts as having the potential to make significant contributions to a variety of military applications. The High Current Electronics Institute in Tomsk is an internationally recognized center of excellence for pulsed power. Both of these activities have demonstrated a willingness to participate in international programs. (See related item under RF DEWs in this subsection.) Another area of Russian research identified as having potential application to pulsed power is pulsed-explosive magnetohydrodynamics. Under a collaborative effort, the Institute of High Temperatures and the High-Energy Density Research Center in Moscow have been developing explosively driven radial electromagnetic hydrodynamics reportedly capable of repetitive operation with 10-kg explosive charges.

Japan has strong capabilities in a number of key areas, including high-temperature superconductivity under the general auspices of the Japan Fine Ceramics Center in Nagoya; high-energy-density electrochemical capacitors (key players include Matsushita, NEC, Toyobo, and Yamaguchi University); electromechanical storage, specifically a composite flywheel storage system being developed by Nippon Steel in collaboration with Mitsubishi and Marubeni Corporation; and solid-state power switching. Japan has strong industrial capabilities in high-power thyristors (Mitsubishi Electric Corporation), and high-voltage metal-oxide semiconductor (MOS) controlled thyristor switches (Toshiba Corporation, reportedly paralleling U.S. developments in this area), and is reported to have ongoing development efforts in SiC devices for high-power, high-temperature operation.

The Chinese appear conversant with the principles and literature of ETC propulsion. Research on energetic particle ignition exposed to hot plasma appears in 17th International Symposium on Ballistics. Researchers at the National Specialized Lab of New Type Electrical Machinery of the Huazhong University of Science and Technology have published research on numerical simulation of compulsators specifically for ETC gun application.

Autoloading meets what are evolving as universal requirements to reduce manning and increase firepower in ground forces. With the general trend toward downsizing, however, few development programs of any significance are in progress. Two programs are pushing the state of the art: the U.S. Army Crusader and the Japanese 155 SP howitzer. This Japanese (N155HSP) 155 howitzer is a fully automatic loading system whose performance objectives are generally comparable to the Crusader's. A prototype reportedly successfully fired at the Army Yuma test range in 1997. This model represents the continuation of a developmental effort begun in 1985. While earlier prototypes used dual rotating magazines, the current version uses a cradle that positions the shells and propellant charges horizontally behind the handling mechanism.

Sweden also has configured and evaluated some innovative tank designs using autoloading. A notable example is the UDES–19, a radical design that uses a fixed external 34-round store and an articulated loading mechanism. Although the Swedish Army has reportedly abandoned these indigenous designs in favor of procurement of the Leopard II, the basic design concepts may still be of interest.

Another autoloading concept is evident in the Austrian Panzerjager SK105 mobile tank destroyer. This system uses a turret designed under license from a French firm, which is also used on the AMX–13 and Brazilian EE–17. A limited ready-load of 12 rounds is stored in two cylindrical magazines. This configuration can deliver very high rates of fire, but the magazines must be replenished from outside the vehicle. This vehicle has been widely sold, and by the mid 1980s was in service in Argentina, Bolivia, Greece, Morocco, Nigeria, and Tunisia.

The Commonwealth of Independent States, notably Russia and the Ukraine, are considered to be world leaders in autoloading. A 125-mm autoloader is standard equipment on its 125-mm armed T–64, T–72, T–8, and T–90 main battle tanks and on the Ukrainian-developed T–84. As is the case in other tank weapons, these autoloaders are generically different from those of the SP 155 howitzer in that they are designed to handle a cartridge round containing both propellant charge and projectile, as opposed to the separate zoned charges used for field artillery.

Despite the increasing emphasis on development and use of large-caliber systems for delivering guided weapons, direct-fire and medium-/small-caliber guns, rockets, recoilless rifles, and small grenade and mortar launching systems will remain critical to both offensive and defensive military operations. Many countries are active in production and international sales of small- to medium-caliber weapons. Among the traditional world leaders in this technology are Germany (Mauser and Rheinmetal), and France, which also has reportedly good capabilities in telescoping ammunition. Numerous other countries have established infrastructures in developing systems based on new technologies, including Austria, Brazil, Egypt, Russia, Singapore, Switzerland, and Sweden.

c *Missiles*

A number of countries (including certain developing countries) have some capability of producing standard explosives such as trinitrotoluene (TNT), cyclotrimethylenetrinitramine, nitroglycerin, ammonium perchlorate, metal fuels, hydrazine, and related compounds for military use. The United States, France, the U.K., and Japan are the world leaders in formulation and production of advanced explosives and propellants.

Advances in hypersonic/hypervelocity (Mach 6–8), shortening engagement cycle times, and increasing system lethality threat-handling capabilities will enhance close combat and short-range air defense missions. The development of hypervelocity vehicles depends greatly on advanced rocket propulsion techniques and on advances in airframe design and G&C. Advances in propulsion technology (specifically air-breathing propulsion) are necessary to support near-term objectives of U.S. Army missile development programs.

In the area of gel propulsion, the United States appears to be the world leader. Russia is reported to have investigated this technology, but apparently has not strongly pursued it. Germany has initiated an effort, and Japan is considering it for military applications. France and the U.K. have expressed interest, but have not as yet begun serious development.

Japan, Germany, and France, followed closely by the U.K. and Russia, have significant experience in the design, manufacture, and testing of air-breathing rocket motors and components. Japan has initiated a broad-based initiative to develop materials and structural/aerodynamic design techniques for hypervelocity transport, the results of which could contribute to this effort. The focus of efforts is toward a multimission KE missile capable of being launched from multiple light platforms and hitting a target with 3–5 times the kinetic energy of tank cannons.

Japan is reported to be developing a high-performance ducted rocket system for antiship cruise missile applications. France is considered world class in air-breathing propulsion. ONERA is very active in European research. They were a primary force in the creation of the Association of European Research Establishments in Aeronautics, a group of seven research establishments created to promote cooperation and exchange. They work closely with other research activities, especially their German and U.K. counterparts, DLR and DERA. ONERA has cooperative programs with NASA, the Army, and the Air Force in aerodynamics and computational processes and with the Russian Central Institute of Aviation Motors and the Central Aerodynamic Institute, specifically in ramjet propulsion and aerodynamics. Micro Turbo (France) produces the high-performance turbojet used in an Army UAV. The Netherland's TNO–PML is also active in a wide range of research in missile propulsion and is studying ramjet-powered projectiles for antiarmor systems.

Tactical propulsion encompasses all aspects of onboard propulsion for the delivery of ordnance, including solid- and gel-rocket motors and air-breathing propulsion for hypervelocity missiles. Liquid-rocket motors and air-breathing missile technologies common to manned and unmanned air platforms (e.g., small, low-cost gas turbine engines like those used on Tomahawk) are addressed elsewhere. Technologies for mixing and loading solid-rocket motors for tactical weapons (typically less than 600-mm diameters) are generally available worldwide. Technologies for larger rocket motors for strategic weapons not as widely dispersed. Technology for development of reduced and minimum smoke formulations has proliferated.

France, Germany, the U.K., and Japan all have varying degrees of investment in hypersonic air-breathing propulsion and in design of critical subsystems. The following are among the highlights offering promise for critical developments:

- French work in C-C composites and applications in high-temperature combustion.
- Japanese efforts in high-temperature structural ceramics, including Si and silicon-nitride compositions.

d *Ordnance*

Any country with an armaments industry can produce simple contact, time, and proximity-sensing fuses. Capabilities to contribute to advanced fusing for programmable/smart ordnance and aimable warheads and for look-down, shoot-down antiarmor weapons are primarily in the U.K. and France, with possible niche capabilities residing in Germany, Italy, and Sweden.

Japan is generally prohibited by its constitution from export sales of weapons, but specific areas where Japanese technology might enhance U.S. Army safing, arming, fusing, and firing (SAFF) capabilities include optical and IR lasers and detectors, MMW components, and ANN and fuzzy logic for use in target detection and aimpoint selection logic.

The 57-mm munition used by the Canadian navy has been selected as a vehicle for demonstration of insensitive munition (IM) approaches. An experimental round, using an explosive

(CX–84) patented by DREV, is reported to have demonstrated performance equal to that of the TNT-loaded round, with significantly improved safety characteristics. Ongoing work includes development of energetic binders and plasticizers for both explosives and propellants, which offer both improved performance and safety.

In SAFF technology, past U.S. programs provide a legacy of world leadership in canister-dispensed munitions and related technology, especially in terms of sophistication, safety, and reliability of design. France, Japan, the U.K., Germany, and Italy follow closely in overall conventional weapon SAFF design and may actually hold slight leads in specific component technologies. Singapore, South Korea, Taiwan, Brazil, India, Sweden, and Switzerland have conventional weapons fusing capabilities adequate to meet many needs. SAFF technologies of other arms producers—notably Russia and China—do not compare, due largely to deficiencies in underlying electronic component design and production.

In terms of safety and reliability of SAFF functions, no other countries approach the ability of the United States, Germany, the U.K., and France. However, any country with the electronics capability to build aircraft radar altimeter equipment should have access to the capability for building a reasonably adequate, simple height-of-burst fuze. China, India, Israel, Taiwan, South Korea, Brazil, Singapore, the Russian Federation, Ukraine, and South Africa have built conventional weapons with design features that could be adapted to more sophisticated designs providing variable burst height and rudimentary ECCM features. (This includes the technology and know-how for gun-shock hardening of electronic components and access to components for miniaturization of small-proximity sensors for submunitions.)

The United States, the primary developer in the area of electronic initiation, holds a significant lead over the rest of the world. In thermal batteries, current technologies appear to be able to provide adequate energy and power densities to meet operational requirements. However, affordability remains a barrier, particularly for large-volume items such as artillery projectiles. In terms of reserve thermal battery technology, the United States and France are world leaders, followed closely by Germany.

IMs are an area of international research, with the primary centers of activity being found in NATO and Japan. Much of the NATO work is visible and accessible to all participants through the NATO Insensitive Munitions Information Center (NIMIC). The NIMIC Website provides references to research activities in the U.K., Canada, and the Netherlands. The French organization SNPE (see below) is generally recognized as world class in energetic materials R&D.

IM WEAPON SYSTEMS

Improved 4.5-inch ammunition round

Stingray torpedo mid-life update

Advanced short-range air-to-air missile

Proposed replacement warhead for Sea Eagle air-to-surface antiship missile

Main battle tank ammunition

Although work in IM is a worldwide endeavor, the United States appears to lead in all aspects of IM. U.S. researchers have pioneered the development of a number of key components and materials. Much of the impetus for early development of insensitive high explosives was driven by nuclear safety issues and by DOE facilities such as Los Alamos and Sandia National Laboratories, which remain at the forefront of these emerging technologies.

France appears to be the most active foreign country in IM, particularly in the areas of reaction modeling sensors and full-scale testing. As noted previously, their goals for MURAT (the French national doctrine regarding less hazardous munitions) are the most ambitious of those under consideration. The Société National des Poudres et Explosifs (SNPE) [http://www.snpe.fr] is recognized as a world leader in the devel-

opment and application of energetic materials (explosives and propellants). The Centre d'AchËvement et Essai Propulseurs et Engins is responsible for testing various propellants developed by SNPE and for their adaptation to missile propulsion subsystems. Areas of IM investigation include full-scale testing of fast and slow cook-off of tactical missile systems and techniques for characterizing and evaluating responses. The Commissariat a l'Energie Atomique is investigating shock and detonation waves in triamino-trinitro-benzine (TATB)/ cyclotetramethylenetetranitramine (HMX) mixtures. One recent study demonstrated the importance of explosive microstructure to the ignition process. More recently, members of the same team applied their quasi-static model to determine the low-velocity impact sensitivity of a mixture of more than 90-percent TATB in a polymeric binder. Experimental results were in good agreement with the mathematical model. It was observed that sensitivity was not significantly affected by temperature. Pyrospace uses hexanitrostilbene in airbag detonation mechanisms.

The U.K. has a long tradition in all aspects of energetic materials and ordnance fabrication. Many of the processes used worldwide for the manufacture of materials like HMX and RDX were developed by the U.K. Since 1990, the U.K. has had a policy for introducing IM in new programs. The U.K. Ministry of Defence Ordnance Board is the focal point for munitions. The office of the Chief Inspector of Naval Ordnance has been particularly active in IM exchanges and discussion.

British Aerospace [http://www.baesystems.com], successor to the U.K. Royal Ordnance Laboratory, claims to be a world leader in IM. They and DERA [http://www.dera.gov.uk] report a wide range of IM activities. Areas of particular emphasis and expertise include full-scale testing and testing of rocket motor structures and explosive trains. Another area of DERA IM-related research is the replacement of conventional elastomeric binders with energetic binder materials. Much of this work has been directed toward improving the aging behavior and physical properties of energetic binders, which are usually inferior to those of the inert binder materials they replace. British Aerospace, Royal Ordnance Rocket Motors, has developed and tested an adhesively bonded IM rocket motor against four environments: fuel fire, bullet impact, slow heating, and 12-m drop test. The last of these, while related to handling and not one of the defined NATO threats, is significant for IM in that the item is subjected to very substantial deceleration shock levels. The Royal College of Militarily Science, Shrivenham, has been particularly active in the NIMIC effort and in the development of standards for IM. Among the specific activities of interest at this facility have been workshops dealing with the reaction of energetic materials and munitions to impinging shaped-charge jets.

Germany's Fraunhofer Institute for Chemical Technology is a world leader in energetic materials and is working specifically in IM areas. Energetic materials are tested at the institute for sensitivity to a variety of stimuli, including shock (bullet impact, shaped-charge impact, and sympathetic detonation effects) and thermal effects (slow and fast cook-off). Related research areas include performance, sensitivity, effect of insensitive high explosives, and characterization of performance and deflagration-to-detonation time in solid-gun propellants.

As noted above, a number of countries are active in warhead design and research, M&S of terminal ballistics, and warhead effects. In recent years, the number and diversity of countries active in advanced warheads, such as EFPs, has increased substantially. A growing number of countries are also involved in research in other types of advanced warheads, including improved shaped charges. Research in these areas is an important indicator of an underlying understanding of the response of materials under high-rate deformation. This understanding

also underlies the development of other types of multipurpose warheads and aimable ordnance, as well as design of effective ballistic protection.

France is very active in both shaped-charge and EFP research, much of the latter at ISL. The EFP work includes simulation of high-density EFP liners (i.e., tantalum) and modeling of aerodynamics of optimized EFPs (in conjunction with the Ersnt–Mach Institute, Germany). The Ersnt–Mach Institute is also independently active across a broad spectrum of research topics relating to warheads and warhead effects, as is the U.K. (specifically the Royal Military College of Science and DERA. Other EFP efforts were identified in Rafael Ballistics Center (Israel), the Terminal Ballistics Research Laboratory (India), and the Aeronautical and Maritime Research Laboratory (Australia).

Japan's constitution limits military activities to self-defense and prohibits the export of military systems. As a result, Japanese efforts tend to be somewhat less visible than those of other countries. Industries identified with development, fabrication, and loading of munitions include Nissan, Aeronautical and Space Division; Kawasaki Heavy Industries [http://www.khi.co.jp/index_e.html]; Nippon Yushi; Asahi Kasei; and Mitsubishi Heavy Industries.

Canada is active in NIMIC and conducts research specific to IM at DREV. These efforts range from chemical formulation to development of specific applications, including warheads, rocket motors, and gun propellants. DREV offers extensive facilities for the preparation and study of all kinds of explosives and propellants in quantities sufficient for meaningful study. It can formulate, process, and characterize explosives and of gun and rocket propellants, including expertise in plastic-bonded explosives, low-vulnerability gun propellants, composite rocket-propellants, melt-cast TNT explosives, and synthesis of energetic polymers.

Scientists at several Chinese institutes are investigating the properties of IMs. Beijing Institute of Technology is looking at nitrogen tetroxide (NTO), TATB, and picylaminodinitropyridine; the Institute of Chemical Materials of the China Academy of Engineering Physics studies TATB; and Xi'an Modern Chemistry Research Institute, which has ties to the China North Chemical Industries Corporation as well as to the military, is looking at NTO and 1,3,3-trinitroazetidine. Nanjing Institute of S&T is investigating TATB and structurally similar compounds.

Norwegian efforts in IM began in 1980. While there has been continuing interest since, emphasis on IM has varied, with performance frequently taking precedence over insensitivity. In Norway, the Forsvarets Forskingsintitutt is reported to have had the greatest involvement in development of new energetic materials and studies of IM. However, industry has also played a key role. For example, Dyno Industrier A.S., Defense Products has been jointly funded by the Norwegian Ministry of Defense and the Swiss Defense Procurement Agency to develop reduced sensitivity, NTO-based, high-explosive compositions.

Most Russian institutions involved with explosives R&D are affiliated with one of three organizations: the Russian Academy of Sciences, the Ministry of Defense, or the Ministry of Atomic Energy. Russian literature has been largely silent on specific efforts toward IM development. It is not certain whether this is due to classification or because operational doctrine does not require its emphasis.

Sweden's BOFORS Explosives and BOFORS Weapons Systems Division have developed IM-based rounds for 40-mm and 57-mm L/70 guns that retain the same level of performance as conventional ammunition, but fulfill more stringent safety requirements. The rounds are con-

sidered IM because they have low-vulnerability ammunition LOVA propellant, insensitive plastic bonded explosive, and hexanitrostilbene igniters and boosters.

The Netherlands has been active in the NATO Insensitive Munitions Information Center (NIMIC), and TNO conducts what appears to be a comprehensive program of research in formulation and processing of explosives, propellants, and pyrotechnics in its Munitions Technology and Explosion Safety Research Division.

The United States has an extensive information base and has traditionally held a modest world lead in the warhead technology area. A large number of countries are ordnance manufacturers, many patterned after the United States' (Japan, South Korea) or the U.K.'s Royal Ordnance establishment (Pakistan, Singapore, India, Sweden). Among major weapons producers, the U.K., France, and Germany have the greatest capability to contribute to innovative developments, followed by Italy, the Netherlands, Norway, Switzerland, and Sweden (the last two in antiarmor).

Russia has had a strong program in conventional explosives and warheads and certainly has an adequate research base in detonation physics and the response of materials to support future developments. Brazil, Canada, China, Egypt, Israel, India, Pakistan, Singapore, South Africa, South Korea, and Taiwan all have arms industries at levels that would permit them to imitate the design approaches, but not necessarily the performance of critical warhead developments in the more advanced countries listed above.

e *Weapons Lethality and Vulnerability*

Two overarching security concerns affect cooperation in this area. The first is the potential compromise of U.S. intelligence collection sources and methods in programs dealing with lethality against specific foreign weapons. The second is operational security of information relating to vulnerabilities of U.S. weapons that might be exploited by a potential adversary to defeat or degrade U.S. systems. Within the limits imposed by these concerns, however, there may be opportunities for cooperative programs. In some cases, foreign participation may fill gaps in U.S. program capabilities. The U.K., France, and Germany all have strong programs in M&S of weapons effects as well as extensive empirical databases. These countries have capabilities in armored systems, with France having a particular niche capability in helicopter structural survivability.

At the theoretical level, M&S of weapons effects and the development of algorithms and techniques are fairly widespread, particularly among traditional NATO allies. Data sharing and cooperation do not typically extend to empirical data on specific weapons against operational systems. The United States has done extensive testing and probably has the largest empirical database upon which to build future critical developments.

Although the details of specific weapons and target responses are closely guarded, there is a considerable body of open international R&D activity in the underlying sciences and technologies needed to enhance weapon effectiveness and characterize target vulnerabilities. France, Germany, and the U.K. are all world leaders in this area. Highlighted institutions include the French–German Research Institute in France, the Ernst–Mach Institute in Germany (vulnerability modeling, including behind-armor effects), and DERA (Fort Halstead) in the U.K.

There is widespread global activity toward advancing the state of knowledge of the underlying principles governing the mechanical response of materials and structures to high-energy rate deformation and ballistic loading. One example is the evolution of "mesomechanics," a field of study that attempts to characterize physical behavior across a wide spectrum of different scales—atomic, microscopic, macroscopic, and structural. This subject was the topic of a recent international conference held in Xi'an. Organizers of the conference listed included Xi'an Jiatong University; Tsinghua University, Beijing; the Chinese Academy of Sciences (China); and the Institute of Strength Physics and Materials Science, Siberian Branch of Russian Academy of Sciences, Tomsk. In addition, the European commission and universities from Australia, Canada, Germany, Greece, Ireland, Israel, Italy, Japan, Korea, the Netherlands, Portugal, Russia, Sweden, and Taiwan are represented on the International Steering Committee.

f *Radio Frequency Directed-Energy Weapons*

Electronic warfare includes any military action involving the use of EM and directed energy to control the EM spectrum or attack an enemy. The three major categories of EW are electronic attack, electronic support, and electronic protection. Directed-energy weapons (DEWs) can be considered a special type of electronic attack that are handled as a separate category to distinguish them from more traditional EW techniques. Laser weapons, RF weapons, and particle-beam weapons are the three main categories of DEW. As a practical matter, only lasers and RF weapons have advanced sufficiently to be of military value. Of these, only RF DEWs are included in this section since there is no ongoing Army research on laser DEWs.

Directed-energy systems are advanced technologies that may completely change the way military missions are organized and executed in the future. In this section, these systems include charged particle beams, neutral particle beams, antiparticle beams, and high-power microwaves (HPMs). High-energy lasers are treated in the section on laser and optics.

Besides the United States, England, France, Germany, Japan, and Russia have had substantial programs in particle beams and particle-beam-supporting technologies in general and have well-developed technical capabilities in the majority of critical elements. England has an extensive program in coil gun and rail gun development, while Germany, Russia, and Japan have some ongoing developmental work in special areas. Electrochemical and ETC gun developments are ongoing in several countries. Japan has an active program in ETC, while England, France, and Germany are involved in some special development of both electrothermal and ETC guns. The leaders in the regenerative liquid propellant gun technology are the United States, Israel, England, and Germany. The United States and Russia are world leaders in the HPM technology, but some important activity is also found in Germany, France, Switzerland, China, and Japan. Sweden, Israel, Ukraine, and Australia are also significantly involved in these activities.

France is a leading producer of HPM tubes. Significant RF source development efforts also exist in the U.K. Several other countries have limited research efforts in this area: Germany, Switzerland, China, Japan, and to a lesser extent, Sweden, Israel, and Australia.

Russia and Ukraine have significant capabilities in RF weapons. The FSU was considered the world leader in HPM at the time of its disintegration. The Russians have concentrated on development of high-power RF generators, such as various types of gyrotrons and klystron amplifiers. The United States has an ongoing R&D effort in multisensor fusion and machine-based reasoning and will be working cooperatively with South Korea (ROK) in this area. The ROK

early efforts on this joint project will be largely theoretical and mostly performed at the university level. Because the later phases of this effort will involve software development and testing, ROK has the potential to make significant contributions. The opportunity, afforded by this joint project, to evaluate operational deficiencies of current technical approaches to automated truth maintenance and for tactical situation awareness is essential. Each nation can focus its limited resources while avoiding duplication of effort. Existing agreements between the United States and ROK provide the vehicle to pursue this cooperative effort.

g *Example Research Facilities*

The following facilities hve demonstrated expertise in weapons technology development:

- Singapore—Defence Science Organization National Laboratories [http://www.mindef.gov.sg/midpa/whatsnew/year97/03oct03.htm]
- NATO—NIMIC [http://www.nato.int/related/nimic/]
- Russia—Izhevsk Electromechanical Work [http://www.iemz.ru/]

6 Soldier and Human Systems

Human systems technologies and methods ensure that military personnel are properly selected, trained, and equipped to perform effectively and safely. The technologies include, but are not limited to, sensors, displays, communications, processors, logistics monitoring, and warrior protection systems. Impacts of these types of technologies include increased unit effectiveness through more effective training; improved ergonomic design of systems, including displays and decision-aiding technologies to enhance mission performance; enhanced warfighter protection; and improved mobility through advances in logistics and sustainment capabilities. Table E–5 summarizes international human systems technology capabilities.

AMC POC

Dr. Rodney Smith
e-mail: rsmith@hqamc.army.mil

IPOC

Ms. Jan Lanza
e-mail: jan.lanza@natick.army.mil

a *Information Display and Performance Enhancement*

Information display and performance enhancement technologies improve situational awareness and the common battlefield picture, synthesizing this picture with the warfighter's relevant experience and tactical knowledge and helping the commander orchestrate the collective and distributed decisionmaking process at every echelon. The primary goal is to maximize information throughput from sensors, processors, and displays to warfighters.

Most developed nations have significant research efforts in information display and performance enhancement. Interest is driven by multiple requirements, including the need for improved presentation of information to match human cognition and improved representation of human performance to improve realism and fidelity of computer-generated forces and "actors" in both simulations and operational systems.

TABLE E–5. TECHNOLOGY DEVELOPMENT—SOLDIER AND HUMAN SYSTEMS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
INFORMATION DISPLAY & PERFORMANCE ENHANCEMENT						
◆◆◆◆+ VRIs Soldier–system interface HPM	◆◆◆◆+ Display Soldier–system interface Ergonomics Performance modeling	◆◆◆◆+ Soldier–system interface HPM	*Japan* ◆◆◆◆+ Displays VR Robotics		◆◆◆◆+ VR display	*Israel, Sweden, Netherlands* ◆◆◆ Human performance measures *Israel* ◆◆ HMD
DESIGN INTEGRATION & SUPPORTABILITY						
◆◆◆◆+ Performance modeling	◆◆◆◆+ Performance modeling Ergonomics	◆◆◆◆+ Performance modeling	*Japan* ◆◆◆◆+ Automated industry/ enterprise design			
SURVIVABILITY & PERFORMANCE ENHANCEMENT						
◆◆◆◆+ Soldier systems (physiological & psychological)	◆◆◆◆+ Soldier systems (ballistic protection)	◆◆◆◆+ Soldier systems			◆◆◆◆+ Soldier systems	*Australia* ◆◆+ Soldier systems (microclimate control)
PERSONNEL PERFORMANCE & TRAINING						
◆◆◆◆+ Dynamic training & simulation	◆◆◆◆+ Dynamic training & simulation	◆◆◆◆	*Japan* ◆◆◆ Distributed training & simulation of complex enterprises		◆◆◆◆+ Simulators & displays	*Australia, New Zealand, Belgium* ◆◆◆◆ *Netherlands* ◆◆◆ Simulators *Finland* ◆◆ Shooter training systems

Note: See page E–6 for legend.

Information management and display efforts develop methods and media to process and deliver task-critical information to individuals, teams, and organizations. Maximizing the flow of information depends on developing time-sensitive, supportable information handling and display components that serve as a visual and auditory human–system interface (HSI) for both weapons and support systems. Developing simulation interfaces is another area of keen interest. Simulations must be of sufficient fidelity to enhance mission planning and to permit diagnostic examination of emerging technologies and concepts. As a result, model development is an important aspect of this work.

A number of foreign countries have significant capabilities in HSI technologies. The United States has ongoing efforts with France and Germany in soldier–system interfaces, especially related to teleoperations. The U.K. has noteworthy capabilities in soldier–system and virtual reality interfaces (VRIs), and Canada (Gallium Software) has capabilities in VR and displays. Israel also has unique expertise in helmet-mounted displays (HMDs). Japan is a leader in displays, VR, and robotics, all of which are needed for teleoperations.

The goals of performance enhancement technologies are to enable soldiers to operate well beyond normal mental, physical, and perceptual capabilities and to enhance performance in stressful, hazardous, time-constrained, inhospitable, and remote environments. Areas of particular interest include computer-aided crisis management decision support, unmanned robotic vehicles, and mobile manipulator platform control. In addition, concepts for battlefield synchronization, on-the-move collaborative techniques, real-time decisionmaking, and visualization for distributed problem solving are becoming increasingly important.

Human performance modeling is a critical factor in meeting future Army requirements. Such modeling contributes to enhanced soldier–system battlefield performance through low-risk, quick-turnaround simulation, permitting rapid assessment of proposed systems concepts. Human performance modeling ranges from anthropometric models of impulse and acoustic detection by the human ear, through cognitive and physical workload assessment, to decisionmaking under stress. France is recognized as a key international source for cooperative research in these aspects of HSI. Negotiations are underway with France on auditory research and ergonomics issues. The U.K. and Germany also have very strong capabilities in human performance modeling; to a lesser but still significant extent, Israel, the Netherlands, and Sweden also have capabilities. Canada has a number of programs to study and model human factors in aircrew, crew stations, and operator–robot interactions.

b *Design Integration and Supportability*

Design integration involves the development and production a fully integrated crew weapon or information system through the use of effective design tools, HSI models and databases, and performance metrics. Human–system performance and cost variables must be part of the design process. Technology capabilities are required in human performance assessment and modeling, tools for enhancing physical accommodation, methods for human error and reliability assessment, and tools for crew station design and testing.

Manpower and personnel integration (MANPRINT) efforts will play an important role in the design integration subarea. Foreign capabilities are similar to the information management and display subarea described above. The U.K., France, and Germany offer the most capabilities in terms of applying performance modeling to systems design. Some of the world-class work that Japan is doing in automating industry and enterprise design may be applicable to the challenging aspects of integrating system-of-systems.

System supportability includes improving affordability, availability, operability, maintainability, and logistical supply to reduce life-cycle support costs. The Army must be able to provide early estimates of manpower, personnel, and training (MPT), as well as associated human performance requirements and costs for HSI, so they can be input to the acquisition and design process. The set of MANPRINT methods and tools are key elements in this effort. The goal is to have validated techniques that are robust enough to permit quantitative tradeoff analyses among various MPT variables and design options. This will allow decisionmakers to examine variations in systems performance as a function of MPT investment.

The growing complexity of weapon systems makes it increasingly difficult to support those systems with personnel who can effectively operate and maintain them. To balance soldier resources and requirements with emerging technologies, research is needed to determine the limits of attention saturation, mental workload, and manpower utilization. This is essential to maintaining full military readiness, availability, sustainability, and effectiveness. U.S.–French

cooperation in ergonomics is directly related to supportability issues. France is sharing modern ergonomic performance-measuring instrumentation and techniques, while the United States is sharing its MANPRINT suite of soldier–system performance enhancement tools.

c *Survivability and Performance Enhancement*

Survivability and performance enhancement technologies support warfighting and peacekeeping mission capabilities through full-spectrum personal protection; troop sustainment, including rations and field feeding equipment; survival and rescue; advanced airdrop (both personnel and cargo); load carriage optimization; and dismounted and mounted warrior systems integration, including warfighter systems analysis. Survivability and sustainability of individual soldiers and small operational groups for the future battlefield and for operations other than war will require advances across a wide spectrum of capabilities. These include ballistic protection, CB protection, signature reduction, enhanced food preservation and delivery, and precision cargo airdrops.

Scientific and technological efforts include nutritional performance enhancement, food preservation, food service equipment, drinking water purification, precision cargo/personnel airdrop, and airbeam technologies for lightweight, rapid-setup shelters. Individual survivability also includes all material and combat clothing systems for protection of the individual warfighter. Areas of particular interest are individual ballistic protection, countermeasures to sensors, laser eye protection, multifunction materials, and textiles. (A special case is biologically derived materials such as spider silk or bioceramics for body armor.)

Cooperative opportunities in individual survivability relate primarily to improved soldier systems. The soldier system focuses on enhancing soldier capabilities in the five areas of lethality, C^2, survivability, sustainability, and mobility. This encompasses everything the soldier wears, carries, and consumes in a tactical environment. France has special expertise in ballistic protection for individual soldiers. The U.K. has strong capabilities in the physiological and psychological aspects of soldier systems. Germany and Canada both have strong capabilities in materials and soldier–system integration. In addition, a niche capability in individual microclimate control has been identified in Australia.

Canada has recognized strengths in many areas of sustainability as demonstrated by the FY96 approved foreign comparative testing of a Canadian generator and multifuel burner. Canada also has significant capability in the CB and gravitational force protection for soldiers and aircrew, as well as developing test rigs for body armor. The Canadian Defence and Civil Institute of Environmental Medicine has developed survey systems to generate user feedback on clothing and protective wear. Other Canadian efforts include the development of personal cooling systems, studying human performance in cold environments, modeling personnel performance in physiological stressful environments, and developing intelligent clothing and equipment sizing systems.

d *Personnel Performance and Training*

PP&T efforts seek to strengthen unit readiness and reduce costs through advances in force management and modeling, selection and classification, human resource development, simulation-based training, training strategies, and training efficiency. Technology developments of interest include the advanced distributed interactive simulation and VR technologies that can have a major impact on individual, collective, joint, or multinational training in all environments.

Other thrust areas are development strategies for selection and classification and leader development, including design of aptitude tests and performance metrics.

Manpower and personnel issues are of concern to all countries wishing to field and maintain an effective military capability. International cooperation in manpower and personnel is taking place through a variety of mechanisms. The United States, the U.K., Canada, Australia, and New Zealand pursue collaborative research and actively exchange information of defense R&D projects through TTCP. Examples of such collaborative research include selection tests for tank gunners and effects of workload levels and stress on decisionmaking. Collaborative research also occurs through the Defense Research Group (Panel 8, Human and Biomedical Sciences) of the NATO Armaments and Research Organization. For example, the United States is gaining valuable information regarding the fielding of computer-based selection tests in Germany and Belgium and on the use of distance learning technologies in European countries.

An important set of training challenges arises from the need to develop strategies for individual and collective training that provide an effective and affordable mix of live exercises and synthetic training environments. Live force-on-force tactical engagement simulation remains a key element of the training strategy for both the United States and its major allies, but the increased lethality and longer ranges of U.S. weapon systems and improved C^4I systems are pushing the limits of current U.S. laser engagement training systems and their corollary test and evaluation instrumentation systems. A key goal will be to develop a set of training technologies (strategies and performance metrics) that adequately reflect emerging communications and information technology, modern warfare conditions, and new doctrine.

A number of foreign countries have significant capabilities in training and simulation technology. Canada, France, Germany, the Netherlands, and the U.K. have made valuable contributions, and each represents considerable leveraging opportunities. Australia has hosted several international simulation conferences and symposia to expand its knowledge, increase its capability, and broaden its use of simulation. The U.K. has established an industrial advisory board to monitor simulation activities in the United States and advise on military use in the U.K. Germany is experimenting with injecting virtual targets into live sights, a key challenge for embedded training and live-to-virtual linkages. Canada's advanced display systems would be useful for all types of simulations, and the U.K.'s and France's ability in human performance modeling and VR technology could enhance battlefield representations. The Netherlands has assumed a prominent role in Europe as a technical expert in the use of training simulation technology and has orchestrated several major demonstrations of advanced distributed simulation technology in support of NATO vision and goals. Israel has significant capability in computer- and laser-based tactical training systems.

Australia, Canada, New Zealand, the United States, and the U.K. have established working groups in VR and distributed simulation under TTCP's Training Technology Panel HUM–2. NATO Army Armaments Land Group 8 is identifying standard agreements for training interoperability among member nations, and NATO Research and Technology Panel Number 8 is investigating human factors issues in the use of VR for military purposes.

e *Example Research Facilities*

The following facilities have demonstrated expertise in soldier and human systems technology developments:

- Canada—Defense and Civil Institute of Environmental Medicine
- Australia—Land Operations Division, Defense Science and Technology Organization [http://www.dsto.defence.gov.au/esrl/lod/index.html]
- Finland—Noptel [http://www.noptel.fi/nop_eng/index.html]
- Netherlands—Command and Control and Simulation Division, TNO–PML [http://www.tno.nl/instit/fel/div2/]

7 Biomedical

Biomedical concerns relate to preserving and optimizing the health and performance capabilities of military personnel in peace and war. Individual service men and women are the most essential and vulnerable component of military systems. Disease and nonbattle injury exceeds battle-related injuries as the major cause of military casualties. The force structure now confronts additional threats from weapons of mass destruction (WMD) exposure to pathogens endemic in developing nations, operational stress, and harsh climates. The existing medical infrastructure in the regions to which troops are deployed is often modest; therefore, appropriate treatment of U.S. personnel requires evacuation to base hospitals at significant distances from the site of injury.

AMC POC

Dr. Rodney Smith
e-mail: rsmith@hqamc.army.mil

SBCCOM POC

Dr. George Famini
e-mail: grfamini@sbccom.apgea.army.mil

MEDCOM POC

Ms. Patricia Showe
e-mail: patricia.showe@det.amedd.army.mil

For humanitarian reasons, and because biomedical technologies are dual use, much of the research and technology is widely shared. Virtually all developed nations (including the U.K., France, Germany, and Japan) have significant national research programs that can contribute to U.S. Army requirements. The spread of AIDS and other diseases, such as Ebola, and the emergence of antibiotic-resistant bacterial strains worldwide have spurred medical and biomedical research. Medical and biomedical research in many nations is not focused on military requirements. However, knowledge related to the prevention, treatment, and control of disease is important to the defense community during deployment to new areas or in response to the biological agent threat. Telemedicine is a related rapid growth area. This technology includes networking of healthcare facilities by satellite and the use of high-resolution video to permit treatment of injured or wounded military personnel at sites distant from high-quality medical care facilities. As physicians become geographically distant from combat arenas and as medics become the primary care providers, telemedicine capabilities are essential to the survival and wellness of the soldier. Table E–6 summarizes international biomedical technology capabilities.

TABLE E–6. TECHNOLOGY DEVELOPMENT—BIOMEDICAL

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
INFECTIOUS DISEASES OF MILITARY IMPORTANCE						
♦♦♦♦ Human and pathogen genome & drugs Tropical	♦♦♦♦ Human and pathogen genomes & drugs	♦♦♦♦ Human and pathogen genomes & drugs	*Japan* ♦♦♦♦ Human and pathogen genomes & drugs	♦♦♦♦	♦♦♦♦ Human and pathogen genomes & drugs	*Switzerland, Israel* ♦♦♦♦ Human and pathogen genomes & drugs
MEDICAL CHEMICAL, RADIOLOGICAL, & BIOLOGICAL DEFENSE						
♦♦♦♦ Vaccines Drugs	♦♦♦♦ Vaccines Drugs	♦♦♦♦ Vaccines Drugs	*Japan, Singapore* ♦♦♦♦ Vaccines Drugs	♦♦♦♦	♦♦♦♦ Vaccines Drugs	*Switzerland, Cuba, Israel, Netherlands* ♦♦♦♦ *Singapore* ♦♦ Vaccines Drugs
MILITARY OPERATIONAL MEDICINE						
♦♦♦♦ Imaging Food additives	♦♦♦♦ Imaging	♦♦♦♦ Imaging Food additive	*Japan* ♦♦♦♦ Imaging		♦♦♦	*Sweden, Israel* ♦♦♦♦
COMBAT CASUALTY CARE						
♦♦♦♦ Blood substitute Biological response modifiers	♦♦♦♦ Blood substitute Biological response modifiers	♦♦♦♦ Blood substitute Biological response modifiers	*Japan* ♦♦♦♦ Blood substitute Biological response modifiers	♦♦♦ Blood substitute	♦♦♦♦ Blood substitute Biological response modifiers	*Switzerland, Israel* ♦♦♦♦

Note: See page E–6 for legend.

a *Infectious Diseases of Military Importance*

This technology area seeks to protect soldiers from infectious diseases normally encountered in a deployed area. A related goal is to return soldiers to duty as rapidly as possible. Infectious diseases pose a particular threat to operational effectiveness because most Americans lack immunity to diseases that are endemic in other regions of the world.

The deployment of forces is frequently associated with increased incidence of illness in persons who have not previously resided in the region. Viral or bacterial disease is present in a high proportion of persons who report for sick call. As the number of forces to be deployed is reduced in "reachback" concepts and the requirement for sustained performance increases, reducing sick call is more important than ever for sustaining force projection capability. Global surveillance of infectious diseases provides a database that can be used to determine what immunization or other protection of individuals is needed prior to deployment. Several agencies gather data on endemic diseases: the Center for Disease Control, World Health Organization (WHO), and Pan–American Health Organization. A comprehensive database of such information can function as a clearinghouse for defense and public health requirements. This database could function as an early warning system for an outbreak of infectious diseases, whether caused by organisms endemic to an area or disseminated by terrorist or nation/state entities. The information would serve to alert pharmaceutical firms and the defense community to increase production of vaccines and antibiotics.

The U.K. has several areas of expertise in tropical diseases. The Liverpool School of Tropical Medicine researches programs in the control and management of malaria; this effort is part of the World Health Organization (WHO) activities in tropical diseases. Novel vaccine approaches are in development at Oxford Bioscience.

The genomics of the human is currently being defined through the Human Genome Project in the United States, the U.K., France, Germany, and Japan, with collaborations in other global regions. The Medical Research Council (MRC) (U.K.), the Centre Nationale de la Recherche Scientifique (CNRS) (France), the German Cancer Institute, and the Gesellschaft Biotechnologische Forschung (GBF) are among the contributors. The definition of the genome of pathogens is underway in many national laboratories and pharmaceutical firms. An example is the proteomic database (SwissPro Protein Database), which is readily available on the Web.

At present all major chemical and pharmaceutical companies (e.g., DuPont, ICI, Elf–Acquitaine, Ciba–Geigy, Smith–Kline) are multinational. Several other nations are noted for capabilities that may be of interest to Army applications. Switzerland and the Netherlands both have world-class pharmaceutical industries. Singapore has some capability, including new bioprocessing facilities. Australia is already a cooperative partner with the U.S. Army Medical Research Institute of Infectious Diseases. Some countries, including Kenya and Thailand, represent opportunities of cooperation because of geographical location of disease occurrence and not because of any resident technical capability.

b *Medical Chemical, Radiological, and Biological Defense*

The objective of the medical chemical defense program is to preserve combat effectiveness by timely provision of medical countermeasures in response to joint service defense requirements. A major challenge is the development of pretreatments (vaccines, immune enhancers, prophylaxis), protectants (antivirals and antibiotics), or antidotes that are effective and safe for human use. Both rapid and long-acting antichemical and antibiological agents are required, as are skin decontaminants and protective compounds. Cooperative programs exist between the U.S. Army Medical Chemical Defense Research Program and agencies in the U.K., Canada, Israel, Germany, Australia, and other nations for the development of technologies to protect soldiers from chemical warfare agents. The primary U.S. programs are concerned with modeling the 3D structure of acetyl cholinesterase in order to design countermeasures to inhibit this enzyme.

The primary goal of medical biological defense is to ensure the sustained effectiveness of armed forces operating in a biological warfare environment. The related tasks include the development of new vaccines, superantigens, sensor systems, antivirals / antibacterials, and immune enhancers. Such approaches will reduce lethality and enhance the return of the soldier to duty.

Most nations with advanced medical care or advanced industrial hygiene and safety capabilities have some level of expertise in personal protection. Nations with extensive pharmaceutical capabilities also have vaccine production capability. The U.K., France, Germany, Russia, and Israel have extensive capabilities in meeting the needs for sustained operational effectiveness.

France has several private and national research centers related to pharmaceutical and vaccine protection against biological agents. Rhone–Poulenc, now merged with Hoechst of Germany, produces and markets drugs and vaccines on the global market. The Institut Pasteur in Paris has an excellent history developing vaccines.

The University of Toronto has expertise in DNA-based vaccine development. Allelix Biopharmaceuticals in Toronto has capabilities in drug and vaccine production. Adherex in Ottawa uses the cell binding characteristics of bacteria to design novel countermeasures. Viron Therapeutics in the U.K. examines the role of viral proteins in turning off immune responses. The definition of these viral inhibition mechanisms can assist in the design of novel immunogens.

Germany has several major efforts in drug development, vaccine production, and design of adjuvants. Gesellschaft für Biopolymer–Berlin has an active program in adjuvant development. The German Cancer Institute in Heidelberg and GBF in Braunschweig have active programs in drug and vaccine development. Hoechst, now a partner of Rhone–Poulenc in France, has an active R&D program in drug development.

WHO has promoted the development of new vaccines. One outcome is the joint effort to produce and market a diphtheria, pertussis, tetanus, hepatitis B vaccine by the National Institute of Public Health and the Environment (RIVM), Bilthoven Netherlands; Bio Farma in Bandung, Indonesia; and Rhein Biotech in Maastricht.

Cuba has two vaccine production facilities, and both are marketed internationally. The Center for Pharmaceutical Chemistry produces vaccines for meningitis type B. The National Center for Scientific Research of Cuba produces anticholera vaccine.

c *Military Operational Medicine*

The goals of this effort are to protect soldiers from environmental injury and material/system hazards, develop safety and design criteria for military systems, sustain individual and unit health under stress (sustained operations conditions), and quantify performance criteria. The technologies include management of sleep, iconography, and food additives (e.g., tyrosine, melatonin) to increase alertness. Germany, Sweden, and former Soviet Union (FSU) states have had extensive programs correlating human physical performance with nutrition and sleep cycles. These programs are primarily sustained in university and sports medicine organizations.

Functional magnetic resonance imaging (MRI), a major advance in this area, permits training of personnel to criteria defined by the user and testing of subjects in simulators. This technology effectively permits visualization of neural activity in an alert, awake human and correlates the activity with sensory input/output, cognitive activity, or muscle tone. Work pioneered in the United States and the U.K. led to the emergence of this field in the neurosciences. Among the nations producing instruments capable of functional MRI are the U.K., the Netherlands (Phillips), Germany (Bruker), and Israel (Elscint). The Oxford Centre for the Functional Magnetic Resonance Imaging of the Brain (U.K.) has good resources related to this technology.

d *Combat Casualty Care*

This program aims at saving lives far forward in the combat arena. Issues of concern include far-forward resuscitation, minimizing lost duty time from minor injuries, reducing unnecessary evacuations from site, and decreasing resupply requirements of forward echelons of care. Canada (Hydro Biotech) has developed a containment system to protect casualties and medical personnel from biohazards.

Technical challenges include overcoming the toxicity of oxygen-carrying hemoglobin and blood substitutes, stanching abdominal bleeding, and applying hemostatic agents to wet surfaces of hemorrhaging wounds. Major efforts have been underway to identify blood substitutes that

have minimal toxicity to recipients. Perfluorocompounds have been tested in the United States, Japan, and other industrialized nations. The Green Cross organization in Osaka, Japan, has a long history of work in this area. Terumo Corporation in Kangawa has efforts in resupply of blood cell components. The Russian Research Institute in Hematology and the Russian Military Medicine Academy, both in St. Petersburg, have programs relating to blood substitutes. The University of Nottingham in the U.K. has an active program evaluating blood substitutes.

e *Example Research Facilities*

The following facilities have demonstrated expertise in biomedical technology development:

- Germany—German Cancer Research Center [http://www.dkfz–heidelberg.de/index_e.htm]
- Netherlands—The National Institute of Public Health and the Environment [http://www.rivm.nl/]
- Sweden—Department of Biomedicine; Nuclear, Biological, and Chemical Defense Division; Defense Research Establishment
- Canada—Allelix Biopharmaceuticals [http://www.allelix.com]

8 Chemical/Biological Defense

The Chemical and Biological Defense (CBD) program includes efforts to develop passive and active deterrents to the use of WMD. These deterrents include chemical and biological (CB) detection, information assessment (including identification, modeling, and intelligence), contamination avoidance, protection of individual soldiers and equipment, and collective protection against WMD. Table E–7 summarizes international chemical/biological defense and radiological technology capabilities.

AMC POC

Dr. Rodney Smith
e-mail: icpa@hqamc.army.mil

IPOC

Dr. George R. Famini
e-mail: George.Famini@sbccom.apgea.army.mil

a *Detection*

Current U.S. Army policy is to not enter contaminated areas. Although the idea of avoiding a contaminated area is still important to the Joint Service program, more emphasis is being placed on detecting and identifying a CB threat prior to arrival into critical areas.

The most rapid changes in technology capabilities are currently seen in the area of detection. Private sector and federal investment is strong. The detection components include point and standoff platforms, sample concentrators, and patterned or digital readouts. Because the technology has applications in the defense arena and in the environmental monitoring, medical, and pharmaceutical industries, it is a dual-use technology. The growth of sensor technology is among the most rapid in all industrial sectors, and it is driven by perceived needs in the medical and environmental health communities.

The identification and detection of biological agents may be achieved by point or standoff systems. The former depends on direct interaction of the sensor matrix with agent materials or extracts; the latter relies on some spectral method used at a distance. Point detection systems function through the use of specific- and high-affinity binding materials (antibodies or other immunological binder; DNA/RNA binders, receptors, combinatorial materials) that will bind to and recognize biological agents of interest. In addition to binding materials, the point detector system includes four components: collector, trigger, detector, and identifier.

TABLE E–7. TECHNOLOGY DEVELOPMENT—CHEMICAL/BIOLOGICAL DEFENSE*

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
DETECTION						
♦♦♦♦ Sensors Microfluidics Lab on chip Proteomics	♦♦♦♦ Sensors	♦♦♦♦ Lab on chip Proteomic Microfluidic	*Japan* ♦♦♦♦ Sensors Humanoids Robotics *China* ♦♦♦ Sensors	♦♦♦ BW detection sensors	♦♦♦♦ Lab on chip Sensors	*Netherlands, Israel, Switzerland, Sweden* ♦♦♦ *Singapore* ♦♦♦ Solid phase micro extraction
PROTECTION						
♦♦♦♦ CB protective clothing, including mask & body cover	♦♦♦♦ CB protective clothing & body cover	♦♦♦♦ CB protective clothing & body cover	*Japan* ♦♦♦♦ Body cover *China* ♦♦♦ Body cover	♦♦♦♦	♦♦♦♦ CB protective clothing & body cover	*Singapore, Israel, Netherlands, Switzerland* ♦♦♦♦ *Sweden* ♦♦♦
DECONTAMINATION						
♦♦♦♦ Biodegradation	♦♦♦♦	♦♦♦♦	♦♦♦♦		♦♦♦♦ Bioremediation	*Israel, Sweden, Finland* ♦♦♦♦
MODELING & SIMULATION						
♦♦♦♦ Weather patterns Computer systems	♦♦♦♦ Weather patterns Computer systems	♦♦♦♦ Weather patterns Computer systems	*Japan* ♦♦♦♦ Weather patterns Computer simulation	♦♦	♦♦♦♦ Weather patterns Computer simulation	*Netherlands, Israel* ♦♦♦♦

Note: See page E–6 for legend.

*Smoke and Obscurants section is not included.

Standoff biological agent detectors detect a threat agent by means of optical or other spectral properties inherent in the agent. These detectors generally rely on light scattering or absorbance of IR light by the target agent. The difficulty is that all life forms (pollen, fungus, bacteria, virus) have these signature materials, so the probability of a false-positive signal is high. France has active programs using laser-light scattering as detection elements, and an extensive program in light detection and ranging (long-range standoff biological detection and ranging) technology.

An operational German system, the Fuchs nuclear, biological, and chemical reconnaissance system, has advanced point-detection capabilities. The United States has joint agreements with Germany for integrating new technologies developed in either nation into the Fuchs platform. The United States, the U.K., and Canada are working to improve the Biological Integrated Detection System by conducting joint test and evaluation procedures. The Czech Republic has contributed elements for detection of nerve agents; Poland has contributed technology related to spore detection. The United States, the U.K., France, Germany, Japan, Switzerland, and Israel have advanced capabilities in the general area of biological sensors. Russia had a significant capability in this arena, but it has degraded significantly during the past 6 years.

Biodetection sensor systems include genomics, proteomics, receptors, and combinatorial materials possessing selective, high-affinity binding characteristics for biological agents. They include patterned surfaces to which the binding materials are attached in an addressable manner. The fluidic systems containing the biopolymers of the biological agent are another sensor compo-

nent, as is the transduction of a binding event, between agent fragment and sensor surface, into an optical or electrical signal and the subsequent alert that a superthreshhold level of agent has been detected.

In the U.K., Brax Ltd. (genomics), Imperial College (microfluidics), and the Laboratory of Government Chemists in Teddington (laboratory on a chip) have excellence in sensor and detector technologies. The Teddington facility has teamed with Glaxo, Wellcome, Kodak, and Unilever. The MRC Laboratories have expertise in genomics and proteomics. Other U.K. corporations with technologies related to biodetectors and sensors include Zeneca and Isis Innovation; the Imperial Cancer Center is a governmental facility with strong capabilities in genomics and proteomics; DERA has expertise in transitioning CBD technologies to defense-related systems.

Corporations and government laboratories in France with expertise in detection technologies include Rhone–Poulenc, CNRS, and Genset. The recent merger between Rhone–Poulenc (France) and Hoechst (Germany) provides major transnational strength in genomics. Rhone–Poulenc (Rho–Bio subsidiary) has an extensive database on genomics of disease resistance in plants. Other corporations with international holdings and cooperative studies include Bio–Merieux, Cazuax, the Centre D'Etudes du Bouchet (CEB), Transgene, Pasteur-Merieux–Connaught, Giat, and Elf–Acquitaine/Sanofi.

Germany has developed capabilities in genomics, proteomics, microfluidics, and mass spectroscopy. The German Cancer Institute in Heidelberg is a leader in profiling gene expression and in production of a chip containing protein/nucleic acid probes. The probes are synthesized on the chip. The proteomic database [http://www.mann.embl–heidelberg.de/Default.html] is a primary source for sensor elements. The GBF in Braunschweig has major research efforts in genomics and proteomics. GBF is cofunded by the private sector and serves as a transition between basic and applied research. Sequenom is a joint U.S.–German venture aimed at developing a DNA chip for a detector. Among the leading microfluidics developers are the Max Planck Institut Colloids and Interfaces in Teltow–Seehof. Another German corporation, Bruker–Franzen, has developed advanced mass spectroscopy electrospray methods for applications in detectors. The merged Hoechst and Rhone–Poulenc entity has capabilities in all areas of biodetection, individual and group protection, and modeling. Other German industries with major strengths in this area include Bayer, Boehringer Mannheim, and Boehringer Ingelheim. Boehringer Ingelheim has a long history of trade with the East European market. Degussa also has valuable niche strengths in this area.

Canada has detector development capabilities in both academia and the private sector. The University of Alberta has an excellent center for developing the "laboratory on a chip." Procyon (London, Ontario) also has capabilities in this arena. The Computing Devices of Canada, Dycor, and Defence Research Establishment–Suffield (DRES) are noted for capabilities as well.

Several Japanese companies have interests in detection systems. Fuji films, Nikon, and Takara Shuzo have capabilities in the area of thin films. The Tsukuba research laboratories, including the NEC Tsukuba facility, has developed technology for miniaturization of sensor/detector elements. These capabilities represent leading-edge technology centers in detection and data fusion. Another important area is the integration of detection systems with robotics for use in areas too hazardous for personnel. Erato has developed a robotic insect model and the Riken Biomimetic Control Center, Nagoya, has biomimetic strength in robotics. Sony Corporation is modeling an in-silico simulation of a biological organism (C. elegans). The Tokyo Institute of Technology and the University of Tokyo are academic institutions with strength in micro-

robotics. Honda Corporation developed a humanoid prototype robot; Mitsubishi Heavy Industries, Sony, and Omron also have humanoid robotics capabilities.

The Groningen Biomolecular Sciences and Biotechnology Institute (GBB) in the Netherlands, has expertise in drug detection. It is partnered with Ciba–Geigy (Switzerland), Hercules (Netherlands), Novo–Nordisk (Denmark), and Roussel–Uclaf (France) in pharmaceutical technologies that have application to detection and individual and group protection. The MESA Research Institute at the University of Twente in Enschede has developed expertise in microfluidics with applications in screening, detection, and drug discovery.

Switzerland has leading-edge capabilities in detection, drug discovery, and development by virtue of its long history of excellence in pharmaceuticals. Large pharmaceutical firms, including Ciba–Geigy, and a new biotechnology industry contribute to this strength. Novartis, which has advanced genomics capability, and the SwissPro Protein Database are centered in Switzerland. Swiss quality control systems for the production of pharmaceuticals use sensor systems that have application to biological agent defense.

Two primary biotechnology entities in Israel are at the leading edge of detector and sensor systems. Yeda Research and Development Company is affiliated with Weizmann Institute in Rehovot; Yeda has a long tradition of developing advanced sensors for various sectors including defense. Technion, in Haifa, has strength in sensor interfaces and prototype production.

Eurona Medica, in Upsala, Sweden, has research programs in gene profiling and drug response. This technology has direct applications to detection and screening technologies. The University of Umea in Sweden is developing new data-reduction techniques for detection. Private sector and national laboratories in the Peoples Republic of China have partnership agreements with several U.S. biotechnology firms. The University of Science and Technology of China has x-ray lithography capability that may be used in the design of sensors. Poland is noted for its efforts in food safety and detection of biologicals in food; Singapore is similarly noted for efforts in water monitoring. Cuba has expertise in vaccine development against meningitis (type B) and cholera; it may have capability in detecting agents that cause the disease.

b *Protection*

Biological and chemical protection includes both individual and collective protection of Army assets. The individual protection capabilities include vaccinations, body coverings, and transport of persons exposed to agents. Post-exposure aspects of individual and group protection include antibiotics, antivirals, antifungal compounds, and immune-enhancing compounds (biological response modifiers). The group protection includes ventilation and air control inside as well as on the surface of vehicles.

Canada, Germany, and France have programs for improving individual protection body covering. These efforts are directed toward identifying leaks in the protective equipment and improving body cooling for persons in the protective gear. Israel has developed several masks that may be protective against biological agents, as well as an extensive civilian mask program. The DERA CBD Sector (U.K.), Defense Science Organization (Singapore), Prins Maurits Laboratory (PML) (Netherlands), and AC Laboratorium Spiez (Switzerland) have active programs developing or testing clothing or body coverings protective against CB agents. Singapore has also cooperated with several countries in providing a test ground for hot and humid conditions.

Current collective protection filters for combat vehicles require periodic replacement. The surfaces and filters must be replaced relatively frequently after exposure to CB agents. After extended use in an attack-free environment, the filters must be replaced at fixed intervals. Pressure swing absorption technology, developed in gas exchange systems, is a primary approach used to achieve collective protection. German expertise in filter system development and U.K. expertise in temperature swing absorption technology provide capabilities related to collective protection. The pressure swing absorption technology was developed by the chemical gas purification industry. Polymer grafting capability in Israel (Yeda Corporation) and Sweden (Center for Chemistry and Chemical Engineering, Lund) has applications to improved design of collective protection systems.

c *Decontamination*

Decontamination is focused on developing new (noncorrosive) capabilities for decontaminating equipment and large areas (such as ports and airfields). One part of this effort is bioremediation—the use of biological organisms to clean up wastes and CB agents. Bioremediation has utility with regard to both cleaning a contaminated area and reducing signatures in a contained environment. The biological organisms resident in the area of the waste material frequently have utility in achieving degradation of the contamination. Pseudomonas is one example of an organism that degrades nitrotoluenes, spent fuels, and other organic waste products. Current chemical methods used to achieve decontamination of soils and waste materials are themselves toxic to the environment in large volumes. Enzymes are also being considered for decontamination of equipment, as are reactive sorbents and several nonaqueous methods.

Several corporate entities have expertise in bioremediation; Bio–Logic Remediation Ltd. in Scotland; GBB and Zeneca in the Netherlands; Eberhard in Kloten, Switzerland; Bioforj in Guelph, Canada; HP–Biotechnologie in Witten, Germany; the University of Karlsruhe in Germany; and GMG International in Sweden. Microbiologists in Tel Aviv have expertise in bioremediation of coastal sands contaminated with oil spills; the Israeli group isolated bacteria from oil spill-contaminated beaches, and the organisms degraded oil. U.S. private sector groups have technology exchanges with some of the foreign firms identified above.

Canada has a strong effort in decontamination, including the reactive skin decontamination lotion and the Canadian Aqueous System for Chemical–Biological Agent Decontamination products. The U.K. has also restarted a fledgling program in this area. Several older technologies from former Warsaw Pact countries are of interest to the large area decontamination problem.

d *Modeling and Simulation*

A large portion of the technology used for M&S is the dispersion of CB agents common to that used for weather forecasting and environmental pollution control. Nations with advanced satellite capability will also have strength in the modeling of CB agents dispersed above ground. These include the U.K., Canada, France, Japan, Germany, Israel, China, and Russia. The technology required for determining and predicting wind flow patterns at discrete altitudes above sea level, on a real-time basis, remains to be developed.

The U.K. and Israel have developed an urban agent dispersion model. The U.K. and Canada have refined current hazard assessment models to include casualty prediction and are moving forward into probabilistic models.

e *Example Research Facilities*

The following facilities have demonstrated expertise in chemical/biological defense technology development:

- France—Pasteur–Merieux–Connaught [http://www.aventis.com]
- Japan—NEC Tsukuba Research Laboratories [http://www.labs.nec.co.jp/Eng/index.html]
- United Kingdom—DERA [http://www.dra.hmg.gb]
- Netherlands—Organization for Applied Scientific Research—Prins Maurits Laboratory (TNO–PML) [http://www.tno.nl]

9 Engineering, Combat Construction, and Countermine

Table E–8 summarizes international engineering, combat construction, and countermine technology capabilities.

TABLE E–8. TECHNOLOGY DEVELOPMENT—ENGINEERING, COMBAT CONSTRUCTION, AND COUNTERMINE

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
CIVIL ENGINEERING & ENVIRONMENTAL QUALITY						
♦♦♦♦+ Environmental protection Bioremediation Regulatory compliance Lightweight bridging Response of conventional structures to blast	♦♦♦♦+ Environmental protection Bioremediation Demil of energetic materials ♦♦♦♦ Survivable structures High-performance construction materials	♦♦♦♦+ Environmental protection Bioremediation ♦♦♦♦ Response of hardened structures to conventional weapons	*Japan* ♦♦♦♦+ Environmental protection Bioremediation Bridging, highways, buildings Infrastructure Crash survivability			*Nordic Group, Israel* ♦♦♦♦+ Environmental protection Bioremediation
MINES & COUNTERMINES						
♦♦♦♦ IMF	♦♦♦♦	♦♦♦♦ Ordnance package design EM interference	*Japan* ♦ Intelligent systems	♦♦♦♦	♦♦♦♦ Demining	*Italy* ♦♦♦♦ Mines

Note: See page E–6 for legend.

a *Civil Engineering and Environmental Quality*

This technology area focuses on critical civil engineering and environmental quality problems related to training, mobilizing, deploying, and employing a force at any location at any time. The goal is to provide an environmentally sustainable, military-unique infrastructure at the lowest possible life-cycle cost.

The problems of meeting national and international environmental standards and of engineering-affordable and -sustainable facilities and infrastructures in a climate of reduced funding are common to all of our potential partners. Remediation of environmental pollution and maintenance of infrastructure are areas of considerable importance to the civil sector as well, and most industrialized nations have active programs in techniques, materials, and M&S to support requirements analysis and design.

Civil engineering subareas include conventional facilities, airfields and pavements, survivability and protective structures, and sustainment engineering. The primary thrust of technologies for conventional facilities is to revitalize and operate DoD's aging infrastructure at an affordable cost. In airfields and pavements, the major effort is to reduce life-cycle costs. Survivability and protective structures address reliable and affordable structural hardening, retrofit hardening, and camouflage, concealment, and deception to increase survivability and force protection, from the foxhole to the deeply buried command structure, against threats from conventional munitions, terrorists, and advanced precision penetrators.

Foreign capabilities of most interest are in the areas of high-performance construction materials (France), material systems and response of conventional structures to blasts (U.K.), and response of hardened structures to conventional weapons (Germany). The U.K. and Germany develop and market military systems for lightweight bridging and other civil engineering applications, and they have sound capabilities in alloys and structural designs for such systems. As mentioned earlier, France has special expertise in developing crash-survivable and energy-absorbing materials. Japan has a significant capability in structural design and in practical engineering of crash-survivable vehicles and structures. Japan also has a large civil structures program (bridges, highways, buildings, etc.) that has military significance.

Environmental quality subareas include cleanup of contaminated sites, compliance with all environmental laws, pollution prevention to minimize Army use and generation of wastes and adverse affects on the environment, and conservation of our natural and cultural resources. The U.K. has been a leading force in the development of international standards for environmental management systems. Many of the current draft International Standardization Organization (ISO) standards are patterned after existing British standards. Japan, the U.K., Germany, France, Israel, and the Nordic Group all have significant efforts in bioremediation—the use of biological organisms or their products (enzymes) to breakdown or neutralize a wide range of contaminants. The French in particular have had a longstanding interest and strong effort in biodegradation and demilitarization of energetic materials. The international community has a growing concern for cleaning up organophosphate-insecticide-contaminated sites. An effective enzymatic treatment for this purpose might also be adopted for decontamination of nerve agents. We can anticipate that growing awareness of environmental effects as regional and global issues and the emergence of international standards for their effective management lead to opportunities for increased cooperation to improve pollution prevention, environmental protection, techniques for monitoring and compliance, and remediation—particularly with EC countries and Japan, which are moving rapidly toward adoption of the ISO 14000 standard.

b *Mines and Countermines*

Humanitarian concerns have led to increasing international pressures to outlaw land mines. At the same time, military forces worldwide see mines as meeting critical mission needs. The growing global concern about increased proliferation of mines points to the need for international development and adoption of new design standards and mine-clearing capabilities.

One potential solution—more intelligent mines and minefields—is of global interest. Opportunities for cooperation in intelligent mine/minefield technologies are found in countries that couple historical capabilities in state-of-the-art land mines with strong capabilities in advanced sensors, electronics, and telecommunications, such as the U.K. and France, followed closely by Italy and Germany. Canada is doing substantial work in the subarea of mines and countermines. An MOU between CECOM and its Canadian defense laboratories counterpart in staffing

will expand cooperation. Russia has been a major operational user of landmines and should have substantial empirical experience from which to draw.

The U.K. has significant strength in all areas relating to intelligent minefields (IMFs), including signal processing and antiarmor weapons. Traditionally, the U.K. has been strong in intelligent systems, and researchers at Fort Halstead in the U.K. are actively pursuing fuzzy logic techniques and fuzzy inference engines to enhance current intelligent command aids. The present system, called "GeKnoFlexE," is a conventional, rule-based implementation designed to simulate battlefield decisionmaking. This will be used as a baseline and testbed for investigating the relative benefits of incorporating fuzzy rules and a fuzzy inference mechanism. The results may provide insight into ways to enhance the performance of operational decisionmaking. Since the current GeKnoFlexE system is completely deterministic, direct comparisons of complexity, behavior, and other performance parameters will be possible.

Germany has strong across-the-board capabilities. It is particularly strong in ordnance package design (including warhead fabrication for antiarmor weapons) and is heavily involved in C^4I efforts to improve interoperability. Strong telecommunications are an essential element in IMF. The International Command and Control Systems Interoperability Project with Germany is part of the Army's strategy for international digitization. Its objectives are to create a joint testbed facility to conduct R&D efforts needed to implement, evaluate, and validate improved interoperability between the U.S. and German (C^2) forces. Within the EC, Germany is recognized as a technological leader in telecommunications.

France also has strong capabilities, particularly in telecommunications. Much of the mobile subscriber equipment design is based on French technology. A current U.S.–French treaty requires multinational fire support from C^2 centers of either nation. In addition, fire-support battalions of either nation may be mission assigned to brigades of the other nation. France has good capabilities in intelligent systems, particularly for real-time operations. As in many other countries, organizations are actively investigating applications of ANNs and fuzzy logic to military systems. Work at the defense firm Matra has been identified as being of interest in this area. France also has strong capabilities in batteries and might be able to contribute to advanced technology to meet primary power requirements.

Israel has strong capabilities in most areas of IMF technology and specifically in one of the critical aspects—acoustic sensors. Acoustics efforts include adaptive beamforming algorithms, sound-cancellation techniques to eliminate platform and wind noise, and neural network algorithms for target identification. Israel has demonstrated sensor fusion techniques that significantly increase the acoustic detection and identification performance of sensors. Israel is reported to be in the final phases of development for advanced helicopter detection, sniper, and mortar location systems.

Japan has the necessary sensor and electronics capabilities to implement an IMF concept. Japan is assessed to be among worldwide leaders in two areas that may contribute to future IMF concepts. The first is in practical application of intelligent systems. Japan's ongoing RWC initiative is heavily invested in neural networks. Second, work in optical ANNs, if successful, has the potential to increase effective processing throughputs by orders of magnitude.

Sweden is nearly on par with the world leaders in most aspects of technology. Ericcson, a recognized leader in communications, has a significant background and experience in the develop-

ment of antiarmor weapons, including mortar-launched EFP munitions. Canada has strengths in C^4I and telecommunications and has strong capabilities in acoustic signal processing.

The countries identified above are working at or near the state of the art; however, the technological building blocks of IMF are widely available. Other countries capable of developing some degree of IMF capability include Italy, Switzerland, Norway, the Netherlands, Russia, Ukraine, India, and South Africa.

Although a number of nations are involved in mine clearing activities, Canada's expertise in countermines is particularly noteworthy. DRES has an ongoing initiative in this area covering a wide spectrum of activities, including remote minefield detection and improved breaching methods. DRES, with support from DREO, is developing a multisensor, teleoperated mine detector. The system uses a sophisticated multisensor data fusion scheme using magnetic, ground-penetrating radar and IR sensors to detect potential mines, and it uses thermal neutron activation technology to confirm the presence of explosives to reduce false alarms. The system has been evaluated in comparative testing and reportedly performed as well as U.S. technology, particularly with respect to false-alarm discrimination

With the recent worldwide visibility of the landmine problem, many nations have taken a new interest in developing close-in mine detection and mine neutralization technologies. Italy and Canada have initiated programs to test and evaluate mine detection equipment. In the countermine area specifically, leaders in developing mine detection and mine neutralization equipment include France, Germany, the U.K., Israel, South Africa, Russia, and the United States. Germany continues to be a leader in EM interference hand-held detectors, with Forster and Vallon. Dornier has developed standoff minefield detection sensors together with Carl Zeiss, using ATR algorithms by the Fraunhofer Institute. Elta of Israel has developed a ground-penetrating radar for use on remotely controlled ground vehicles. Both Israel and Russia have been leaders in developing advanced mechanical and spoofing technologies to be mounted on ground platforms. South Africa has developed new methods of using multiple canines for mine detection and of providing blast protection for countermine vehicles. Canada and the U.K. have recently invested heavily in humanitarian demining detection technologies and systems. Austria and Australia are noted for capabilities in these areas as well.

c *Example Research Facilities*

Canada—DRES [http://www.crad.dnd.ca/] has demonstrated expertise in engineering, combat construction, and countermine technology development.

10 Materials, Material Processes, and Structures

Advances in materials and processes are integral objectives of a number of ASTMP programs, including materials for aeropropulsion, characterization of structures for rotorcraft, ballistic protection for soldier systems, materials and structures for hypervelocity missiles, and structures for ground vehicles. Table E–9 summarizes international materials/processes capabilities.

a *Material Processes for Survivability, Life Extension, and Affordability*

The Army's materials, processes, and structures program provides enabling technologies to construct every physical system or device used by the Army. This program provides unique solutions and options that increase the level of performance and durability and reduce the maintenance burden and life-cycle costs of all Army systems. Material technology focuses on

materials with superior properties required for use in structural, optical, armor and antiarmor, CB and laser protection, and infrastructure applications. All classes of materials are included—metals, ceramics, polymers, composites, coatings, energetic, semiconductors, superconductors, and electromagnetically functional materials.

As the table illustrates, a number of countries have strong capabilities in advanced materials. The U.K., France, Japan, and Germany have expertise in metal alloys and composite materials. Noteworthy here is the special capabilities that France is developing in carbon-carbon (C-C) and other ceramics and in the design of crash-survivable structures (noted elsewhere in this annex). In addition, Israel has niche capabilities in metal alloys and organic matrix composites.

TABLE E–9. TECHNOLOGY DEVELOPMENT—MATERIALS, MATERIAL PROCESSES, AND STRUCTURES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
MATERIAL PROCESSES FOR SURVIVABILITY, LIFE EXTENSION, AND AFFORDABILITY						
♦♦♦♦ Metal alloys Composites Polymers Lightweight engineering structures Smart structures Embedded sensors Control of composites processing ♦♦♦♦+ Welding & joining; beryllium processing	♦♦♦♦ Metal alloy Composites Ceramics C-C ceramic part fabrication Energy-absorbing structures Smart structures Bridging Control of composites processing	♦♦♦♦ Metal alloys Composites Ceramics Functional gradient coatings Engineering structures Smart structures Embedded sensors Bridging Control of composites processing	*Japan* ♦♦♦♦+ Ceramics Composites Polymers Ferrous alloys Polymer processing Engineering structures Bridging Embedded sensors *China* ♦♦♦♦+ Metal alloys Composites ceramics *India* ♦♦+ Metal alloys Composites ceramics *ROK* ♦♦♦+ Tungsten beryllium processing	♦♦– Welding Joining Ti Structures Ion-beam coating Structural ceramics ♦– Ti alloy	♦♦ Ceramics Composites	*Israel* ♦♦ Metal alloys Organic matrix composite *Netherlands* ♦♦ Ceramics *Austria* ♦♦ Refracting metals *Australia* ♦♦ Composites
MANUFACTURING TECHNOLOGY						
♦♦♦♦ Cooperative efforts—CASE tools; industrial robotics			*Japan* ♦♦♦♦+ Fuzzy logic for process control ♦♦♦♦ Industrial robotics *China* ♦♦♦+ Hot isostatic pressing CVD Boron and carbon fibers MMCs	♦♦– Welding Joining		

Note: See page E–6 for legend.

Japan has been and is expected to continue to be a major developer and producer of fibers and matrix feedstock for advanced polymer composites that are essential for many advanced materials. Japan has also maintained its leadership position in the development of ceramic- and polymer-based composites. The driving forces behind the effort in the R&D of advanced composites are the aircraft industry, space program, and defense industry. The overall scope of Japan's advanced composites research is not as extensive as that in the United States, but the quality in some respects is comparable. Japan is a world leader in "fine ceramics"—high-purity ceramics with specific performance characteristics, as opposed to bulk ceramics that might be employed for ballistic protection.

In Europe, the BRITE/EURAM program has 35 percent of its effort dedicated to materials and technologies for product innovation, 14 percent to technologies for the aeronautical sector, 14 percent to technologies for other transport means, and 37 percent to production technologies. Emphasis is placed on three themes:

- Materials with wide-ranging application—priority will include nanostructured materials, new and improved structural and lightweight materials for construction, transport and high-temperature materials, ceramics, ceramic matrix composites (CMCs), and biomaterials.
- Materials production and transformation processes—production of fine and specialty chemicals, minerals, metals, polymers and their composites.
- Sustainable use of materials—environmental and safety impact of new materials, materials that are easy to cycle, waste management, and new applications of renewable raw materials.

Germany is among the world leaders in structural ceramics. Much of its emphasis has been on developing materials for automotive and aerospace applications. Research centers include the BeaTec application center machining technology for advanced materials (Fraunhofer Institut für Produktionstechnologie IPT Aachen), Fraunhofer Institute for Ceramic Technologies and Sintered Materials, IKTS Dresden and Ceramics Department at Cologne, and the German Aerospace Research Establishment Materials Research Institute.

The U.K. program includes research at University of Birmingham Advanced Materials Department; the School of Industrial and Manufacturing Science, Cranfield University [http://www.cranfield.ac.uk/sims/]; the Department of Materials, Queen Mary and Westfield College, London [http://www.materials.qmw.ac.uk/]; the Oxford Centre for Advanced Materials and Composites [http://www.materials.ox.ac.uk/research/index.htm], University of Oxford; the Department of Engineering Materials, University of Sheffield [http://www.shef.ac.uk/uni/academic/D–H/em/]; and the University of Nottingham. The U.K. also has considerable expertise in the defense establishment and in the private sector directed specifically toward lightweight armor applications of ceramic materials. The U.K. advanced ceramics project [http://www.ceram.co.uk/] conducts research across a wide array of topics, including several specifically related to armor: aluminum nitride for armor applications, hot-pressed B_4C for armor applications, injection molding of silicon nitride, and fabrication and evaluation of dense sintered SiC.

France has traditionally had a strong program in high-temperature ceramics and in armored systems. The Geopolymer Institute, University of Picardie at Saint Quentin, is involved in research dealing with the geosynthesis of inorganic molecules, geopolymer chemistry yielding high-performance ceramics, fire-proof composites, ceramic tooling, and special and high-performance concrete.

The Netherlands maintains research programs in technical ceramics, including the Centre for Technical Ceramics in the Department of Solid-State Chemistry and Materials Science at the

Eindhoven University of Technology (where extensive research in Sialon materials is reported) [http://www.chem.tue.nl] and in the Technical Ceramics subgroup of the Research Group of Materials Science and Engineering [http://www.phys.rug.nl/mk/research], at the University of Groningen.

Canada has a variety of university research programs in ceramics, including work at the Technical University of Nova Scotia, [http://www.dal.ca/research/index.html] and in the Ontario Centre for Materials Research–Ceramic Processing Facility at McMaster University Hamilton, Ontario [http://www.mcmaster.ca/home.html]. In addition, there are are at least two established Canadian suppliers of soft body armor tested to U.S. National Institute of Justice (NIJ) standards. These firms have the resources and the incentive to develop more advanced armor configurations to meet competition from other suppliers who have begun to market composite ceramic/ballistic fabric body armor.

China is building a large composite materials S&T capability with research on polymer matrix composites (PMCs), metal matrix composites (MMCs), CMCs, and C-C composites. China is also heavily involved in work on functional composites, microstructures and interfaces, fatigue and fracture, and properties characterization. The principal performers of this work are the Beijing Institute of Aeronautical Sciences (BIAM) and the Shanghai Institute of Ceramics (SICCAS). In addition, there are at least 12 other universities and institutes involved in this research. China is very interested in cooperative programs with researchers around the world and has instituted a number of agreements.

India is involved in a strong research program in composite materials, particularly PMC; some MMC effort is also in progress. The principal laboratories performing this research work are the NAL; the Indian Institute of Science, Bangalore; and the National Physical Laboratory. Although one of their major goals is to establish strong indigenous capabilities, India is still dependent on foreign nations for assistance, and thus they are very interested in establishing worldwide cooperative agreements in specific areas.

The vast Russian materials S&T establishment is slowly deteriorating because of economic difficulties. Some institutes (such as the Paton Metallurgical Center) still exist, although many of the leading researchers have left. Russia is very interested in any foreign cooperative agreements that would bring some funding into the country.

Materials processing includes all technologies by which raw or precursor materials are transformed into useful materials or components with the requisite properties and at an acceptable cost for Army applications. These technologies include casting, rolling, forging, sintering, polymerization, composite lay-up and curing, machining, and chemical vapor deposition. Coating processes are of special interest because they affect many devices and components. Ion-beam-assisted deposition and pulsed-laser deposition are two areas of keen interest. Improved process control techniques are also sought, especially related to resin-transfer-molded composites and Smartweave armor materials.

Several foreign capabilities are of interest in the materials processing subarea. The U.K. has strengths in welding and joining. Germany has unique capabilities in explosively formed projectile (EFP) and other warhead metallurgy, as well as processes for deposition of functionally gradient materials. France has special skills in high-density tungsten carbide ceramics that have potential for armor technologies. Austria also has tungsten processing research of interest. The European BRITE/EURAM program includes projects related to composite structures such as

design tools for advanced composites, manufacturing of complex or hybrid composite structures, and reliability and quality. The main goal of these efforts is cost reduction.

Compared to U.S. research institutes, the Japanese have placed more emphasis on processing/ fabrication science. The Japanese composites industry has played a leadership role in advancing textile-preforming technology based on weaving, braiding, knitting, and stitching. A considerable interest exists in combining resin transfer molding, resin film infusion, and pultrusion techniques with fabric preforms for polymer composites manufacturing. The technologies are fairly well developed in industry.

Ongoing activities in Japan include work in microwave curing and low-cost manufacturing based on resin film infusion, resin transfer molding, and automated tape placement. This work is being carried out in collaboration with U.S. industry. Other notable innovations in Japan include five-axis weaving, which is enabling the production of wider 3D woven fabrics for ballistic and impact resistance, and a braiding/pultrusion system that enables the production of high-performance composites at low cost. Japan has developed improvements in the processing of CMCs through the polymer pyrolysis route. The quality of products is better than that of products fabricated via the chemical vapor deposition route. The continuing improvement of the quality of high-temperature ceramic fibers, the availability of polymer precursor materials, the fiber surface treatment technology, and the development of sealants have all contributed to advancements in CMC technology.

Formerly strong Russian capabilities in welding and ion-beam coating are declining. South Korea has a noteworthy program in tungsten penetrator technology that could be beneficial to the United States. Specific heat treatment processes for tungsten alloys have been developed that offer the potential to enhance impact strength for penetrators. China's BIAM and SICCAS establishments are pursuing a wide range of processing technologies such as hot isostatic pressing, self-propagating synthesis, spray atomization, codeposition, and liquid infiltration.

This subarea focuses on developing structural elements with a high level of structural integrity that are inspectable, are analyzable, and can survive the harsh combat environment. To be cost effective, the design must integrate advanced structural concepts that are compatible with mass production manufacturing technologies. Japan is noted for having developed products with complex shapes and thick sections on a routine basis using fully automated machines.

The structures must also be designed to specific vibration and noise levels to maintain crew comfort and a low noise signature. Particular emphasis is on design tools, modeling, failure and fatigue, and life prediction analysis. In addition, developing NDE techniques for identification and quantification of defects and anomalies in composite structures is important. Most European nations and Japan have extensive capabilities and programs in NDE technologies.

A growing area of worldwide research interest is smart structures—instrumented structural designs that adapt to external conditions and stimuli to optimize performance. Closely related to this is the use of embedded sensors (usually based on fiber optics) for monitoring performance and structural conditions. The U.K., France, and Germany have significant capabilities in this area and offer potential opportunities for cooperation.

b *Manufacturing Technology*

Manufacturing technology focuses on technologies that will enable the industrial base to produce reliable and affordable materials and products. It requires integration of all aspects of manufacturing from raw materials through design and integration of components, subsystems, and systems. In the future, international developments are likely to drive greater standardization in manufacturing engineering support tools, including CASE, virtual prototyping, and enterprise integration and control technologies. Already we are seeing rapid growth in technologies for distributed design and management of very complex enterprises in highly industrialized countries, notably Japan, the U.K., France, Germany, and throughout the EC. This trend will be further supported and enabled by the growth of the Internet and its underlying telecommunications infrastructure. Ultimately we can expect to see a seamless integration of distributed M&S with enterprise operation, which will further speed the international exchange of advanced manufacturing capabilities.

China's BIAM and SICCAS claim to have established small-batch production capabilities. BIAM produces boron fibers and B/Al composites using hot isostatic press procedures. BIAM also claims to be producing SiC particulate (SiCp)/Al alloy composites. SICCAS claims to have established a pilot line to produce 1,200–1,500 g of carbon-fiber-reinforced aluminum using domestically produced carbon fibers. BIAM is also working in the area of carbon-fiber-reinforced magnesium.

c *Example Research Facilities*

The following facilities have demonstrated expertise in materials, materials processing, and structures technology development:

- Europe—Basic Research for Industrial Technologies in Europe–European Advanced Materials Program
- China—Beijing Institute of Aeronautical Sciences
- Canada—Structures, Materials and Propulsion Laboratory, Institute for Aerospace Research
- India—National Aerospace Laboratory

11 Sensors and Electronics

This section is divided into two areas: sensors and electronics. Sensors are critical systems for intelligence gathering and situational awareness. They are the multispectral "eyes and ears" for our forces. Electronics are enabling for developing components critical to military applications, such as lasers or display technologies. The battlefield environment reviews the impact of the terrestrial and lower atmosphere environment on sensors and systems. Table E–10 summarizes international sensors, electronics, and battlespace environment technology

a *Sensors*

The topic of sensors encompasses a wide range of diverse physical phenomena and technology, including seismic/acoustic ground sensors and EM sensors in all regions of the spectrum, from extremely low-frequency magnetic anomaly detection to space-based UV and even shorter wave optical devices. Sensor technologies also include associated capabilities for acquiring and processing sensor data to derive useful information regarding the operating environment, as well as the location, identity, and activities of friendly and adversary forces.

TABLE E–10. TECHNOLOGY DEVELOPMENT—SENSORS AND ELECTRONICS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
			SENSORS			
			RADARS			
♦♦♦♦	♦♦♦ Optical switching of microwave power	♦♦	*Japan* ♦♦♦♦+ Electronic components		♦♦	
			ELECTRO-OPTICAL			
♦♦ Optical processing	♦♦♦♦+ IR FPA Laser sensors Multidomain sensors	♦♦♦ IR FPA Laser sensors	*Japan* ♦♦♦♦+ Photonic devices Laser applications ♦♦ Image Intensifiers *ROK* ♦ Thermal Imaging			*Netherlands* ♦♦♦♦ Image Intensifiers
			ACOUSTIC, MAGNETIC, & SEISMIC			
♦♦♦♦+ Acoustic sensors Seismic	♦♦ Seismic					*Israel* ♦♦♦♦ Acoustic sensors
			AUTOMATIC TARGET RECOGNITION			
♦♦♦♦ Signal processing CID	♦♦♦♦ Signal processing CID	♦♦♦♦ Signal processing CID	*Japan* ♦♦♦ Signal & image processing *ROK* ♦			*Israel* ♦♦♦♦ Target recognition Signal processing
			ELECTRONIC DEVICES			
			INTEGRATED PLATFORM ELECTRONICS			
♦♦♦♦ Vehicle integration	♦♦♦♦ Multisensor integration	♦♦♦♦ Vehicle integration				
			ELECTRONIC MATERIALS			
♦♦♦ SOI, SiC	♦♦♦♦ SOI ♦♦♦ SiC	♦♦♦ SOI, SiC	*Japan* ♦♦♦♦+ SOI, SiC *China* ♦♦♦ *ROK, Taiwan* ♦♦ SOI, SiC	♦♦♦ SiC ♦♦♦ SOI		*Sweden* ♦♦ *Czech Republic, Netherlands, Israel* ♦ Current & predicted weather
			MEMS			
♦♦♦	♦♦♦♦	♦♦♦♦	*Japan* ♦♦♦♦+ *China* ♦ *ROK, Taiwan* ♦♦	♦♦	♦♦	*Switzerland, Netherlands* ♦♦♦ *Belgium, Sweden, Norway, Greece, Spain* ♦♦

TABLE E–10. TECHNOLOGY DEVELOPMENT—SENSORS AND ELECTRONICS (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
PORTABLE ELECTRICAL POWER						
♦♦♦♦ Batteries Rotating machinery HTS	♦♦♦♦ Batteries Fuel cells Rotating machinery	♦♦♦♦	*Japan* ♦♦♦♦+ *China* ♦♦ *India* ♦ *ROK* ♦	♦♦♦– Fuel cells Rotating machinery	♦♦♦+ Fuel cells Electromechanical storage	*Israel, Italy, Spain* ♦♦ *Austria,, Belgium, Australia, Denmark, Netherlands, Poland, Ukraine, Switzerland* ♦

Note: See page E–6 for legend.

Radar is the primary sensor for all-weather detection of air, ground, and subsurface targets. It includes wide-area surveillance radars, tactical reconnaissance radars, and airborne and ground fire-control radars. Areas of special interest involve the phenomenology of ultra-wideband (UWB) synthetic aperture radar to enable detection and classification of stationary targets that are subsurface or concealed by foliage or camouflage. Foliage-penetration and ground-penetration systems are the major goal. UWB techniques are also in use in biomedical applications. Most radar research is applicable to military applications. Major technical challenges include understanding wave propagation in background/clutter environments; developing high-power, low-frequency, and wideband system capability; and developing components and algorithms to support high-probability detection and classification with low false-alarm rates. Affordability is a major issue because sensors are so prevalent on the battlefield.

RADAR ISSUES

Real beam search on-the-move targeting against stationary ground targets

Buried target detection

Enhanced spatial resolution

MMW antennas and scanning

Affordability

The U.K., France, and Germany, and to a lesser extent, Japan and Israel all have significant capabilities and niches of excellence. Noteworthy highlights include France's expertise in optical distribution and switching of microwave energy and Japan's world leadership position in electronic components. Monolithic microwave integrated circuit components are especially important for millimeter wave (MMW) radars, and the U.K., France, Germany, and Japan all have strong capabilities in this area of technology.

EO ISSUES

Growth and processing of thin-film materials for uncooled detectors

Monolithic integration of detector, readout, and processing modules

Material growth and processing for multicolor FPAs

Fusion algorithms for multidomain sensors

Performance against countermeasures

Multidomain signature databases

Diffractive optical element design

Integration of diffractive optical elements, detectors, and post-processing circuitry

Affordable and effective laser hardening against multifunction, multiband lasers

EO sensors provide passive/covert and active target acquisition (detection, classification, recognition, and identification) of military targets, and also allow military operations under all battlefield conditions. Platforms include combat personnel, ground combat and support vehicles, tactical rotary-wing aircraft, manned/unmanned reconnaissance aircraft, and BMD/TMD. EO sensors are increasingly important in weapon systems of all kinds.

France is recognized as a world leader in state-of-the-art IR focal plane arrays (FPAs). Their work on HgCdTe large-area staring arrays could be important for future multi-domain smart sensors. The Army Research Laboratory and scientists from LETI (Grenoble, France) are cooperating to

develop techniques to grow buffer layers on Si that would allow integration of the HgCdTe detectors and Si readout in much larger arrays. A new technique is being investigated that promises far lower defects for much larger arrays. France also has special capabilities in short-wavelength (visible and UV) lasers that are very important for some optical countermeasures and standoff biological agent detection. Appropriate laser media are required to take full advantage of advances in laser diodes and diode pumping technologies. The Université de Lyon has special expertise in highly efficient laser emission and extensive knowledge of UV-emitting materials.

Japan is a world leader in all aspects of photonics and is strongly positioned in laser applications. Their camouflage, concealment, and deception technology dominates consumer electronics and may provide future leveraging opportunities for military applications. Germany has made significant progress in processing IR images and in multisensor integration. At the Fraunhofer Institute in Freiburg, considerable research is conducted in quantum well and superlattice materials for detectors spanning the spectral region from UV to long-wave IR.

The U.K. has special expertise in optical processing, optical components, and optoelectronics (OE). Photonic processors using this technology offer inherently high bandwidth, compactness, power efficiency, and immunity to EM interference. The noninterfering nature of light and its propagation characteristics lend themselves to future massively parallel, high-speed information processing. Finally, the Netherlands has special capabilities in second-generation image intensification that could be of value. The United States has diverted its major effort to production of third-generation image intensifiers based on III–V compound semiconductor photocathodes. The Netherlands has continued to improve the multi-alkali photocathodes.

ACOUSTIC, MAGNETIC, SEISMIC SENSOR ISSUES

Advanced target identification algorithms

Multitarget resolution

Detection

Platform and wind-noise-reduction techniques

Compact array design for long-range hearing

Acoustic, magnetic, and seismic sensors provide real-time tracking and target identification for a variety of battlefield ground and air targets. Advances in digital signal processing devices and algorithms have led to significant improvements in acoustic sensors, making them more feasible and affordable. Attended and unattended systems have application against both continuous signals (such as engine noise) and impulsive signals (such as gun shots). Acoustic sensors involve the use of microphone arrays to detect, locate, track, and identify air and ground targets at tactical ranges. Target information from multiple acoustic sensor arrays is digitally transmitted to a remote central location for real-time battlefield monitoring. Enhanced hearing for individual soldiers is another important area, and techniques to extend the soldier's long-range hearing and frequency response are being developed.

Most modern armies have some ongoing work in battlefield acoustic sensors, with no one country having a dominant capability. The U.K. and France offer strong capabilities related to seismic sensors, and Israel provides unique opportunities in acoustic sensors. Current efforts in acoustics include adaptive beamforming algorithms, sound cancellation techniques, and neural network algorithms for target identification. Israel has been developing advanced helicopter detection, sniper, and mortar location systems based on acoustic sensing. The United States has been conducting joint exercises with the Israeli army, and future cooperation will provide potential solutions to acoustic propagation problems, long-range target detection algorithms, and detection in the presence of wind and platform noise.

The goal of automatic target recognition (ATR) sensors is to provide sensors with the capability to recognize and identify targets under real-world battlefield conditions. ATR systems will allow weapon systems to automatically identify targets (and friendly forces), which will increase lethality, reduce the number of costly weapons used, and eliminate or reduce the cost of losses from friendly fire. The technical challenge is to provide high identification rates with very few false alarms for a large number of target classes. Supporting technologies include processors, algorithms, and development tools, including M&S. Current efforts focus on single and multiple sensor ATR algorithm development.

Most countries have active development programs aimed at enhancing ATR capabilities. Underlying feature extraction and pattern recognition algorithms are common topics of academic research. Adaptation of these algorithms for effective military use demands access to specific target and threat characteristics, information that is closely held by all nations to protect sensitive collection methods and sources. Several areas are of special interest for possible cooperative efforts. Japan has done extensive work in visual systems for industrial robots and in Kanji character recognition. While not directed to military ends, the underlying techniques may be of interest. The U.K., France, and Germany have strong capabilities in signal processing for ATR and combat identification (CID), and are close enough allies to share some sensitive target/threat information. Germany has particular expertise in CID of friendly troops that is important for reducing fratricide and improving situational awareness. France has special expertise in ATR algorithms for use in multisensor (forward-looking IR, MMW, and possibly laser radar) systems that could be helpful in developing real-time multisensor techniques. In addition, Israel has strong capabilities in target characterization that could be applicable to a number of efforts, including signature measurements in radar/MMW, signature rendering in the visual and IR regimes, and target-acquisition modeling for imaging IR sensors. The United States has held a cooperative signature workshop with Israel that covered a number of areas associated with ATR, including topics on characterization of target/clutter, synthetic scene-generation modeling, target acquisition model enhancement, dynamic measurements using super high-resolution MMW, and model validation.

Integrated platform electronics focuses on the integration of technologies, disciplines, standards, tools, and components to physically and functionally integrate and fully exploit electronic systems on airborne (helicopters, RPV, and fixed-wing), ground, and human platforms. Integrated platform electronics can result in dramatic cost and weight savings while providing full mission capability. The major technical challenge lies in determining an architecture that is sufficiently robust to readily accept commercial technology innovations. Improving reliability, an important challenge, can lead to reduced logistics and deployment burdens while containing support costs. In addition, standardized image-compression techniques and architectures are of current interest to permit transfer of images with sufficient clarity and update rates to support digitization of the battlefield.

Cooperation in this area leads not only to enhanced performance, but also contributes to standardization and interoperability of coalition forces. Those countries most advanced in development and production of advanced military vehicles offer the best potential for cooperative efforts. The U.K. and Germany have special capabilities in vehicle integration that is of interest, and France has special expertise in multisensor integration that is relevant to integrated platform electronics.

b *Electronic Devices*

Electronics plays a crucial role in battlefield supremacy, enabling or affecting virtually every aspect of warfighting. Electronic devices comprise the following major subareas of technology: EO, MMW components, RF devices, electronic materials, microelectronics, MEMS, nanoelectronics, and portable power sources.

Microelectronic technology is one of the key areas that gives the United States superior military capabilities. These technologies, used in the production of every weapon system in the U.S. arsenal, enable dramatically higher performance and reliability with smaller size and weight. Lithography involving wafer delineation, resist processing, and maskmaking are prime determinants of feature size, and hence density of integrated circuits, and therefore are one of the most critical elements in achieving the high speed and high density required for military systems.

Lithography is the key technology driver for the semiconductor industry. Relevant capabilities include the extension of optical lithography to 180-nm design rules, x-ray and electron beam direct write down to 50 nm, and extreme UV lithography using 10- to 14-nm soft x-ray photons. Japan is the world leader in lithographic development. The Association of Super-Advanced Electronics Technologies (ASET) is a government-funded consortium of 24 companies established in 1996. The ASET program is concentrated in the areas of electron beam direct writing, super-fine synchrotron radiation lithography, ArF excimer laser lithography, and super-high precision mask fabrication.

Lucent Technologies, Inc., Applied Materials, Inc., and ASM Lithography Holding N.V. (Netherlands) are cooperating in accelerating the development of Scattering With Angular Limitation Projection Electron-Beam Lithography. It is emerging as a viable choice for production lithography generations below 180-nm critical dimension technology and as a production-worthy manufacturing tool for building future generations of silicon chips. Several of the world's leading semiconductor companies also have expressed interest in supporting this effort.

Integrated processing has become the newest technology driver for the semiconductor industry, with cluster tools as the conceptual force. Cluster tools can be used for plasma-enhanced chemical vapor deposition (CVD), dry etch, high-pressure oxidation, rapid thermal anneal, and numerous other processes. They can be used either as a batch system performing one process or as a system doing sequential processing steps. Anelva (Japan) is one of the leaders in batch-type cluster processing equipment. Only Japan manufactures a complete range of microelectronics production equipment. It is the world leader in the development and production of lithographic equipment. France, Germany, the Netherlands, and the U.K. produce some types of production equipment. None produces a complete line of equipment, although a few items are rated at the state of the art. Liechtenstein/Switzerland produces the greatest variety of microelectronics production equipment. Although South Korea and Taiwan have large integrated circuit production industries, both countries are in the process of establishing their own capability to manufacture state-of-the-art production equipment.

A rapidly developing technology is the use of semiconductor processing for fabricating MEMS devices. These include sensors and actuators that are fabricated using integrated circuit production processes. Advanced device and process concepts exploit integrated, colocated actuators, sensors, and electronics to achieve new functionality, increased sensitivity, wider dynamic range, programmable characteristics, and designed-in reliability and self-testing. MEMS inserted into weapon systems, ranging from smart munitions and sensors to high-maneuver-

ability aircraft and friend-or-foe identification systems, will bring new levels of situational awareness, information to the solider, and precision strike capability. R&D and production are widespread, with the United States, Europe, and Japan in the forefront of both. European countries in various consortiums such as NEXUS are spending approximately $350 million yearly on R&D, concentrating mainly on the biomedical field. Small countries such as Sweden, Norway, Denmark, Finland, Greece, Spain, Ireland, and Hungary have small, concentrated R&D. In Japan, most R&D programs are supported by the Ministry of International Trade and Industry (MITI) and the Micromachine R&D Center. Japan's R&D is widespread, with major programs in biomedical technology, robotics, sensing, actuators, displays, and printers. MEMS activity in Canada is basically centered on university research; in the last few years, however, industry has become interested in MEMS and its applications. Institutes such as the National Optics Institute, Telecommunications Research Laboratories, and the Alberta Microelectronic Centre have fostered much of the industrial activity by providing links to university research.

This technology area also includes the preparation and processing of new and current electronic materials, from the purification of the basic elements to the final wafer or substrate material ready for device fabrication. They include silicon on insulator (SOI) made by high-energy implantation of oxygen into a heated silicon substrate and SiC for rad-hard and high-temperature applications. An important military application of SOI is its increased radiation hardness, particularly to the areas of dose-rate survivability and single-event upset. SiC-based electronics and sensors can operate in hostile environments where conventional Si-based electronics (limited to 350°C) cannot function. SiC's ability to function in high-temperature, -power, and -radiation conditions will enable large performance enhancements to a wide variety of military systems and applications. These include high-current, -voltage, and -speed requirements of CW and pulsed-electrical subsystems in emerging hybrid-electric and all-electric combat vehicles. Soitec of France is a major player in developing and applying this technology. Soitec is in partnership with silicon giant Shin–Etsu Handotai (Japan) to develop SOI for the future 300-mm market. The Microelectronics Laboratory at the Catholic University of Louvain (Belgium) is a leading academic center on SOI technology. Epitronics, a business unit of Advanced Technology Materials, Inc., and the Advanced Technology Research Laboratories of the Nippon Steel Corporation (Japan) have announced the development of advanced 8-inch separation by implantation of oxygen (SIMOX) silicon wafers. Mitsubishi Materials Silicon Corporation is in partnership with Ibis Technology Corporation, the leading manufacturer of IBIS 1,000 high-current oxygen implanters and a major supplier of SIMOX wafers. Epigress of Sweden is a major producer of reactors for SiC as well as devices and process technology in SiC. Swedish efforts include work being done at the Royal Institute of Technology and ABB. Other countries with large R&D efforts are Germany, Japan, the U.K., and South Korea.

Portable electric power is one of the most essential components for Army operations. Although the soldier is more familiar with the problems of encumbering power supplies, reduction in size and weight with increased performance, reliability, and survivability is just as critical for mobile platforms. Examples of critical parameters for a potential power source source are energy density, activation time, self discharge, and in some cases fuel.

As the era of the digital battlefield unfolds, there is a growing need for smarter and more self-reliant individual soldiers. This amplifies the demand on computing, communications, and overall situational awareness. As a result, man-portable power requirements increase with estimates ranging from 50 to 500 W. Future subsystems that will require electric power include enhanced hearing, night-vision devices, computers, voice and data communications, helmet

displays, individual navigation, weapon rangefinders, and individual climate control. In addition, environmentally friendly power supplies are highly desirable, as are the minimized accompanying thermal, acoustic, and EM signatures. The most promising near-term technologies for the soldier are solid polymer Li-ion batteries and proton exchange membrane (PEM) fuel cells.

Mobile platform power encompasses the generation of primary or auxiliary power for hybrid- or all-electric military vehicles, remote facilities (manned and unmanned), or sensors. These platforms combine the prime propulsion and onboard electrical power generation functions. Such an energy system has operational advantages of reduced signature, increased energy density, lower weight and volume, and greater reliability and flexibility in configuration.

Solid polymer Li-ion batteries are an ideal solution for portable power. They utilize a plastic electrolyte or polymer with carbon electrodes and are very flexible, enabling these batteries to be molded into most any configuration. Their ability to be conformed to curved surfaces, as well as commercial-sector-driven production, makes this an extremely ambitious and affordable future technology.

Li-ion batteries are commercially produced in China, Denmark, France (Saft), Germany, Japan, South Korea, Taiwan, and the U.K. These batteries are needed to satisfy the current thrust in EVs and to control the space battery market. Japan is a world leader in virtually all aspects of portable electrical power, with strength in batteries, fuel cells, and power-control devices.

Other technologies address portable power. Fuel cells, an alternative to internal combustion engines, reduce acoustic signatures and vibration and are environmentally friendly. Fuel cells are classified by their electrolyte and operating temperature: solid-oxide fuel cell (650–1000°C), molten-carbonate fuel cell (650°C), phosphoric-acid fuel cell (200°C), and PEM fuel cell (25–90°C). PEMs are currently the only viable fuel cell option for man-portable power because of reduced startup times, minimal thermal and IR signatures, and smaller volume. Alkaline and phosphoric-acid fuel cells, however, may be utilized in larger portable power constructions (e.g., electric vehicles (EVs)). Ballard Company of Canada is the world leader in the development of PEMs, with strong competition from Japan and Germany. Companies in many countries are working this technology primarily for developing EVs. Continued commercial development will expedite affordability for military applications. In Japan, Toyota has invested $500 million over 5 years, while primary R&D centers are in Germany (Daimler–Benz and Siemens), Norway (Norsk–Hydro), Sweden (Volvo), the U.K. (Vickers), Italy (DeNora), Spain (ICP, ICV), Switzerland (Scherrer Institute), and Denmark (basic research) are primary centers of R&D.

Rotating machinery consists of engines, turbines, and flywheels. For portable power, micro-engines or flywheels can provide power or storage, respectively. Portable electric power on the battlefield may require up to several megawatts. As a primary energy source, even the best engines consume their own weight in fuel within approximately 10 hours. Hence, operational system weight is a function of fuel storage in providing electric power, and as a result, fuel supply will dominate logistics. Many foreign countries have significant capabilities in the different aspects of rotating machines. Austria, France, Germany, Italy, Japan, and the U.K. all have significant strengths in high-power-density, middle-distillate engines. Deutz of Germany has particularly strong capabilities in advanced diesel engines. In electric motors, generators, and alternators, Russia, Switzerland, Germany, Japan, and the U.K. all have significant capabilities. In electromechanical storage, Canada, France, Germany, Japan, Russia, Ukraine, and the U.K. all have significant capabilities. Much of this interest is based on EV development. The German firm Magnet–Motor is recognized for flywheel development.

High-temperature superconductivity (HTS) is enabling for breakthroughs in EV propulsion. Areas of application are motors, fault current limiters, magnetic energy storage, and transformers. Much research, however, has gone specifically into HTS wire. Copper wires generate waste heat (which cannot be reclaimed) and resistive loss, reducing system efficiency. In addition, these wires have limited capability for carrying large currents. Japan is the world leader in developing HTS devices such as superconducting motors, generators, magnetic storage, and HTS wire, with research development at Showa Electric Wire and Cable Corporation, Tohoku University, Toshiba Corporation, Matsumura Laboratory, Center for HTS (University of Tokyo), and the Electrotechnical Laboratory. The European Network for Superconductivity has participants from many countries, the majority of which include France (10), Germany (19), Italy (11), Spain (6), and the U.K. (9). Complementary members include Austria, Belgium, Denmark, Finland, Israel, Norway, Sweden, Switzerland, and the Netherlands. In addition, an international effort has been aimed at developing an Nb_3Sn HTS conductor for the International Tokamak. Germany has strong capabilities in HTS, including generic technologies (materials, magnets, cryogenics), energy research (superconducting generators), and special expertise in medical technologies (MRI, biomagnetic measurements). Russia has shown strong capability in high-magnetic-field research. Additional activities (mostly in joint efforts with United States or Japanese firms) involving HTS wire and cable are underway or beginning in Denmark, Italy, South Korea (Pohang Superconductivity Center), and Switzerland.

c *Example Research Facilities*

The following facilities have demonstrated expertise in sensors and electronics technology development:

- United Kingdom—DERA Image, Pattern, and Information Processing [http://www.dra.hmg.gb]. Several research groups within DERA include DERA Computer Vision and Image Processing Group (Chertsey); DERA Image Processing and Interpretation Group (Malvern); DERA Pattern and Information Processing Group (Malvern).
- Korea—Center for Electro-Optics
- South Africa—CSIR [http://www.csir.co.za/]
- Canada—Defense Research Establishment—Ottawa [http://www.crad.dnd.ca/highlights/dreo_e.html]
- Netherlands—Organization for Applied Scientific Research—Physics and Electronics Laboratory—Sensor and Weapon Electronics [http://www.tno.nl/instit/fel/div3/feldiv34.html]

12 Battlespace Environment

The battlespace environment technology area encompasses the study, characterization, and prediction of the terrestrial and lower atmosphere environments to assess their impact on personnel, platforms, sensors, and systems. The goal is to enable tactics and doctrine to exploit that understanding and optimize new system designs. The technologies and capabilities addressed in this section are critical to realizing the JCS long-term strategy for information superiority and dominant battlespace knowledge. Table E–11 summarizes international technology development in the battlespace environment area.

An understanding of battlefield environments and effects is essential to all aspects of a military system's life cycle, from M&S for design, through mission planning and rehearsal, to actual configuration and programming of sensors and weapons in execution. Here, cooperative international programs are needed to ensure that coalition forces can interoperate effectively with a

TABLE E–11. TECHNOLOGY DEVELOPMENT—BATTLESPACE ENVIRONMENT

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
			TERRESTRIAL ENVIRONMENTS			
♦♦♦♦ All	♦♦♦ All	♦♦♦ All	♦♦ All	♦♦ Cold regions	♦♦♦♦+ All	*Finland, Norway, Sweden* ♦♦ Cold region *Switzerland* ♦♦ All *Israel* ♦ Topography *Italy* ♦ All
			LOWER ATMOSPHERE ENVIRONMENTS			
♦♦♦ All	♦♦♦ Current and predicted weather	♦♦♦ Current and predicted weather	♦♦♦♦ Current and predicted weather	♦♦ Current and predicted weather	♦♦♦♦ All	*Denmark, Netherlands, Sweden, Switzerland* ♦♦ Current and predicted weather *Israel, Italy, Finland* ♦ Current and predicted weather

Note: See page E–6 for legend.

common and consistent understanding of the battlespace and with an ability to receive and process environmental information required to execute the battle.

At the overall C^4I system level, the United States has explicitly addressed this area in such efforts as the Advanced Battlespace Information System study. This has given the United States a significant advantage in specific application of knowledge of environmental effects in the battlespace.

a *Terrestrial Environment*

Terrestrial environment is subdivided into two subcategories: cold region engineering and topography. Cold region engineering focuses on militating against the dramatic effects of winter weather on operations conducted by the U.S. Army. To do this, effective decisionmaking tools, mission planning/rehearsal, and knowledge of how sensors, systems, materials, and personnel perform in cold environments are required. This challenge is not confined to the effects of temperature; it also includes the detrimental effects of snow, ice, and the state of the ground, whether frozen or thawing. This last challenge greatly affects the projection and mobility of forces, mine clearing operations, and earth excavation required for force projection and construction.

Snow, ice, and frozen ground alter the propagation of acoustic and seismic energy and interfere with thermal signatures, greatly reducing the effectiveness of weapon systems and sensors. Icy conditions change fixed- and rotary-winged aircraft performance; affect safe operation of equipment on roads, airfields, and bases; affect the ability to communicate; and impact power sup-

plies and engine startup. Technical challenges relate to developing and validating models of these phenomena and finding ways to enable operations to continue in spite of them. Most northern countries have significant capabilities and programs in cold environment research, in particular, Canada, Norway, Finland, Sweden, and Russia. Several groups include the Scott Polar Research Institute (University of Cambridge, U.K.), the Cold Research Technology Center (University of Technology, Lule, Sweden), and the Robots and Sensoristics group within Italy's Antarctic Research Program. Smaller programs exist in more temperate countries through Arctic and Antarctic research expeditions.

TOPOGRAPHIC ISSUES

Identify terrain features automatically

Develop a total force positioning and navigational capability

Achieve 3D, dynamic, multispectral scene visualization

Generate terrain and weather environments in near real time

Topographic research focuses on better understanding the terrain through improved data generation, analysis, and representation. Efforts are needed to provide technology for rapid digital terrain data generation, terrain visualization, terrain analysis, data management, and realistic mission rehearsal and training. Topographic capabilities are found in many European countries, Japan, and Israel. For example, one software group (Skyline Software) in Israel has marketed a digital terrain package that simulates static and dynamic 2D and 3D objects and weather phenomena, such as fog and clouds.

Technical challenges in this area relate to transport and diffusion of gases and particulates, atmospheric flow, measurement systems that resolve microscale dynamical structures, dynamic and optical characteristics of aerosols and instrumentation for their detection and analysis, and remote sensor concepts and software. Germany has world-class capability in aerosol research, in particular the Gesellschaft für Aerosolforschung (the Association for Aerosol Research), which was the world's first society completely devoted to aerosol research. Canada is a world leader in all areas of terrestrial environment research. The U.K. has strong capability in all areas as well, with France and Germany following as an additional source of European activity.

b *Lower Atmosphere Environments*

Lower atmosphere environments research focuses on atmospheric measurements, data ingest and distribution, analysis of forecast data, weather prediction, atmospheric propagation effects, weather for simulation, and development of weather decision aids. Three technology thrusts are current battlespace weather, predicted battlespace weather, and decision aids.

For maximum situational awareness, accurate and timely information on current weather and atmospheric conditions over the battlefield is critical. One of the technical issues is the need for short-notice, up-to-the-minute weather forecasts anywhere in the world. Remote sensing and existing meteorological sites and services will be enabling for this task. Further technical issues include continued research in remote sensor algorithms, meteorological satellite data extraction accuracy, and dynamics of the atmosphere. Most countries have capability in these areas, with particular excellence noted in the U.K., Canada, Germany, France, and Japan.

Prediction of battlespace weather not only concentrates in the temporal domain, but the spacial as well. Basic research focuses on modeling processes, transport, and diffusion spanning all scales, including optical effects caused by the turbulence in the atmosphere such as scintillation on propagating waves. The integration of ballistic, aerosol transport, and diffusion models into weather prediction codes and the integrated meteorological system is a desired goal. Most coun-

tries with advanced weather technology capabilities are actively researching weather prediction and atmospheric phenomenology.

The whole of these data should be presented such that a decisionmaker is at ease and has maximum confidence in selection and employment of battle parameters such as weapons and other materials. Weather impact decision aids will allow a commander to employ weather as a combat multiplier for U.S. forces. A major objective of this effort is to develop real-time weather and environmental models that will provide common weather effects, features, and phenomena for all services. Milestones include incorporating the impacts of acoustics, illumination, propagation, obscurants, terrain-coupled wind transport, and weather forecasts. Essentially, weather impact decision aids will translate conventional battlespace weather information such as clouds, visibility, and temperature into specific performance information for mission planning and execution. For example, one group in New Zealand has a mailing list for people involved in the merging of AI with meteorology, with many subscribers from around the world [http://www.mcs.vuw.ac.nz/comp/Research/met–ai/]. Outside the United States, little work is available in decision aids applied to weather modeling. Canada is the leader in this area, with the U.K., France, and Germany providing the only additional work.

C INTERNATIONAL COOPERATIVE OPPORTUNITIES IN BASIC RESEARCH

POC

Mr. Stephen Cohn
Army Research Laboratory
AMSTL–TT–IP
2800 Powder Mill Road
Adelphi, MD 20783–1197
e-mail: scohn@arl.mil

Access to international capabilities in basic research offers a potential vehicle for both near- and long-term return on investment. Within the overall Army S&T strategy, one key objective is to emphasize high-leverage opportunities, fostering partnerships where we anticipate the best prospects for sustained excellence in the sciences leading to technology development. This includes cooperation with both foreign government and industries to access niches of technical excellence that can best be coupled to existing and future Army technology goals. This section provides a snapshot of international basic research capabilities and trends having potential to address one or more of the long-term research goals identified in Volume I, Chapter V, of the ASTMP. Many of the identified present and potential cooperative research opportunities overlap those highlighted in the previous section and indicate prospects for long-term partnerships and further cooperative advances based on existing programs or new initiatives. In addition, examples of research facilities doing world-class work in areas of interest to the Army have been identified.

The following discussion and trend tables clearly portray the international scope of S&T. As might be expected, opportunities for cooperation in basic research are far more pervasive and widely dispersed than those for applied research in technology discussed above. Increased global accessibility of scientific information is such that no researcher is out of touch with his or her field. Collaborative research across international boundaries is commonplace.

Taken as a whole, the trends charts indicate a high and growing level of scientific research capabilities abroad in virtually every aspect identified as important to the U.S. Army. This suggests the importance of an international cooperative strategy that can effectively encompass both immediate opportunities and long-range cooperative partnerships.

1 Mathematical Sciences

Basic research in applied analysis and physical mathematics directly contributes to the modeling, analysis, and control of complex phenomena and systems active within the Army. Applied mathematicians define practical boundaries, set the framework of analysis, and act as collaborators for scientists and engineers on many development projects. It is often the case that seemingly unrelated research affects the development of critical technologies. The classic example is the influence of advances in control theory on the development of nonskid brakes.

Many nations show significant capability in a number of areas identified as having potential impact on the future of Army technologies. This is consistent with the fact that many advanced applied mathematics efforts involve only a small number of researchers and have minimal hardware requirements. Thus, even nations without an extremely powerful industrial or research base can have a few specific points of excellence in mathematics.

Germany, France, and the U.K. are all considered being on par with the United States in a number of areas of mathematics research. Each of these countries is noted for developing partnerships between academic and industrial groups working on mathematical problems directly related to modeling and manufacturing issues. In general, Canada and Japan are also working at or near this high level. Both China and India exhibit strong potential research efforts, which are constantly improving and will conceivably soon be world leading. Russia shows a declining capability, largely due to lack of resources. For example, though many important numerical methods for modeling physical phenomena were developed in the Soviet Union in the 1950s and 1960s, current research is no longer considered to be world leading. In addition, Ukraine is noted for a traditional weakness in more basic research and tends to be stronger in development areas. Many other small countries have very strong mathematical talents, including Holland, Denmark, Hungary, Israel, Poland, Romania, Greece, Sweden, and Norway. Significant efforts are also underway in the Pacific Rim (especially Singapore and Malaysia) to develop mathematical research enterprises, but these are not yet of world-class stature. Table E–12 summarizes international research capabilities for each major mathematical science research area.

a *Applied Analysis*

Research in applied analysis contributes to the modeling of physical processes critical to the development of new technologies in a variety of fields, including smart materials, flow control, electromechanics, and optics. For example, computational fluid dynamics (CFD) studies in the U.K., Canada, and Israel can contribute significantly to missile, rotor, and explosive design.

b *Computational Mathematics*

Many specific areas of computational mathematics hold promise for military applications. Research in numerical methods and optimization is the basis for many advances in fluid dynamics, material behavior, and simulation of large mechanical and computational systems. Advanced work in finite element analysis in France and Germany can be applied to the problems of the design and function of complex mechanical structures.

c *Probability and Statistics*

Research in probability and statistics, especially stochastic analysis and statistical methods, is integral to the development of simulation methodologies, data analysis systems, and complex image analysis technology, including new approaches to computer vision for ATR. Fuzzy logic

TABLE E–12. BASIC RESEARCH—MATHEMATICAL SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
APPLIED ANALYSIS						
♦♦♦♦ Fluid dynamics	♦♦♦♦ Dynamic systems, Digital image restoration, Partial differential equations	♦♦♦♦ Fluid dynamics, Nonlinear dynamical systems	*Japan* ♦♦♦ *China* ♦♦+ *India* ♦♦ Fluid dynamics	♦♦♦ Mechanics	♦♦♦	*Israel* ♦♦♦ Fluid dynamics
COMPUTATIONAL MATHEMATICS						
♦♦♦♦	♦♦♦♦	♦♦♦♦	*India* ♦♦♦♦ *Japan* ♦♦♦ *China* ♦♦	♦♦	♦♦	*Sweden* ♦♦♦ Numerical optimization *Israel* ♦♦♦ Computational physics
PROBABILITY & STATISTICS						
♦♦♦♦	♦♦♦♦ Levy processes	♦♦♦♦	*Japan* ♦♦♦♦ Fuzzy logic *India* ♦♦♦♦ *China* ♦♦	♦♦♦	♦♦♦+	*Austria* ♦♦♦ Fuzzy logic
SYSTEMS & CONTROL						
♦♦♦+	♦♦♦♦ Control theory	♦♦♦♦	*Japan* ♦♦♦+ *China, India* ♦♦	♦♦	♦♦	
DISCRETE MATHEMATICS						
♦♦♦	♦♦♦♦ Linear algebra, Network flows, Symbolic computing	♦♦♦	*Japan* ♦♦♦ *China* ♦♦	♦♦	♦♦+	*Hungary* ♦♦ *Czech Republic* ♦♦ Computational geometry

Note: See page E–6 for legend.

research in Japan is an example of international research that can significantly contribute to Army goals in these areas.

d *Systems and Controls*

Systems and control theory work have also been used as the basis for the development of computer systems, as well as applications in robotics. Research areas include work in control in the presence of uncertainties, robust and adaptive control for multivariable and nonlinear systems, and distributed communication and control. France is considered a world leader in control

theory research. The U.K., Germany, Japan, Canada, China, and Russia have significant capabilities in this area as well.

e *Discrete Mathematics*

Also of interest are international research efforts in linear algebra (France) and computational geometry (Czech Republic), which are applicable to the development of new computer network hardware and software platforms.

f *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in mathematical sciences:

- Europe—ERCIM [http://www.ercim.org/index.html]
- United Kingdom—Basic Research Institute in the Mathematical Sciences [http://www.uk.hpl.hp.co.uk/brims/]
- Japan—Research Institute for Mathematical Sciences, Kyoto University [http://www.kurims.kyoto–u.ac.jp/]
- Russia—Euler International Mathematical Institute [http://www.pdmi.ras.ru/EIMI/]

2 Computer and Information Sciences

Computers and information systems are pervasive in virtually all military systems and operations and are essential for maintaining the present leading position of U.S. military capabilities. The computer and information sciences research area addresses fundamental issues in understanding, formalizing, acquiring, representing, manipulating, and using information. The advanced systems, including the software engineering environments and new computational architectures facilitated by this research, will often be interactive, adaptive, sometimes distributed or autonomous, and frequently characterized as intelligent. Table E–13 summarizes international research capabilities for each major computer and information science research area.

a *Theoretical Computer Science*

Theoretical computer science is directed at extending the state of the art of high-performance computers, an enabling technology for modern tactical and strategic warfare. Research in this area includes development of formal models underlying computing technology, optimization of input/output communications, and design of new computing architectures and parallel systems. Although the United States is the world leader in most aspects of theoretical computer science, many other nations show strong capabilities, including Germany, the U.K., Canada, Israel, France, Russia, Poland, and Sweden.

b *Software Engineering*

Formal methods of software engineering are the software parallels to improving the computer hardware addressed in computer studies. U.S. software development has been a driving force in enhancing the overall tactical and strategic capabilities of the U.S. armed forces. The United States has been the world leader in computer science and most areas of software development that contributes heavily to systems engineering and systems integration capability, an overwhelming strength for U.S. military. However, a number of countries have capabilities in various aspects of the overall science. Canada has world-class capabilities in software prototyping,

TABLE E–13. BASIC RESEARCH—COMPUTER AND INFORMATION SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
THEORETICAL COMPUTER SCIENCE						
♦♦♦ Mathematical programming	♦♦	♦♦♦♦ Mathematical programming	*Japan* ♦	♦♦	♦♦♦♦ Theory of computation	*Israel, Netherlands* ♦♦♦♦ *Poland* ♦♦♦ *Sweden* ♦♦
SOFTWARE ENGINEERING						
♦♦♦♦ Requirements engineering Software reuse	♦♦	♦♦♦♦ Requirements engineering CASE	*Japan* ♦♦ Software reuse	♦♦	♦♦♦ CASE Software process improvements Verification and validation	*Sweden, Denmark Netherlands* ♦♦♦ *Australia* ♦
KNOWLEDGE BASE/DATABASE SCIENCES						
♦♦♦♦ Database management	♦♦	♦♦♦	*Japan* ♦♦	♦–	♦♦♦ Database management	*Sweden, Netherlands* ♦♦♦
NATURAL LANGUAGE PROCESSING						
♦♦♦♦ Speech recognition Automated translation	♦♦	♦♦♦♦ Speech recognition	*Japan* ♦♦	♦	♦♦ Symbolic computation	*Sweden, Netherlands* ♦♦♦♦

Note: See page E–6 for legend.

as well as being active in most other areas. India is becoming strong in software prototyping, development, and evolution by virtue of knowledge transfer by U.S. companies employing Indian subsidiaries and subcontractors for software development.

c *Knowledge-Based/Database Sciences*

The U.K. is a leader in most areas, with extensive capabilities in knowledge base/database science. Other countries have niche capabilities (e.g., Sweden, the Netherlands). Russia's previously strong capabilities in all areas of computer and information sciences are gradually declining because of budget constraints and aging hardware.

d *Natural Language Processing*

Natural language processing has taken on an increased importance with the use of multinational/multilanguage forces in the field. The need for rapid communication between such forces is essential to the efficient and safe military cooperation between them. Germany has numerous universities engaged in natural language processing, making it the most active country in the world, outside of the United States. The U.K. is also a leader in most areas of natural language processing, with many of its universities having advanced research programs. Various universities in Sweden, in addition to the Royal Institute of Technology, have programs relating to natural language translation. France and the Netherlands are also quite advanced and have active programs in language processing. Commercial interests are active in bringing research to the market, particularly in the U.K.

e *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in computer and informantion sciences:

- European Consortium—The European Network in Language and Speech [http://www.elsnet.org]
- United Kingdom—Center for Speech Technology Research, University of Edinburgh [http://www.cstr.ed.ac.uk/]
- Sweden—Department of Numerical Analysis and Computing Science, Royal Institute of Technology [http://www.nada.kth.se/index–en.html]
- Canada—Department of Computer Science, University of Waterloo [http://www.math.uwaterloo.ca/CS_Dept/homepage.html]

3 Physics

Basic research in physics broadly supports advanced technology developments by providing insight into the nature and interaction of energy and matter and contributes to technologies with a wide range of civil and military applications. Areas of interest to the U.S. Army include nanoscience, photonics, and processes and technology related to obscured visibility, novel sensing, optical warfare, and image analysis enhancement. For example, this research enables ongoing advancement in microminiaturization and optical subsystems. This will then improve sensor capability and continue development of image analysis and target recognition systems. As Table E–14 shows, a wide range of countries possess capabilities in the major physics research areas.

a *Nanoscience*

The objective of nanoscience programs is to develop the capability to manipulate atoms and molecules individually, assemble them into nanometer-sized devices, and exploit the unique physical mechanisms that operate in these devices. Nanoscience has potential applications in a wide range of civil and military technologies. This includes both improved materials and electronics.

In materials, nanoscience research is directed at developing lighter and stronger structures, advanced lubricants, abrasive-resistant materials, biosensors, etc. Research in Fullerenes and nanotubes is included in these efforts, as well as coatings deposited using nanomaterials.

In electronics, research includes studies in quantum devices, microlithography, and molecular electronics. The goals of these programs include ultra-high-speed devices that consume less power, ultra-high-speed computers, alternative storage mechanisms for computers, and field emission cathodes. Much of this involves research in submicron lithography, offering smaller, faster devices that consume less power.

b *Integrated Sensory Science*

The U.S. Army's ability to operate under conditions of poor visibility is enhanced by improving sensing capabilities. Recognition systems that utilize only spatial information are severely limited in their ability to detect objects with low contrast or in environments containing camouflage or deception. Multispectral and hyperspectral IR imagers promise to provide sensor input that can be exploited to improve the performance of recognition systems in these circumstances. Integration of radar sensors further improves recognition and targeting. Novel and improved

TABLE E–14. BASIC RESEARCH—PHYSICS

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
NANOSCIENCE						
♦♦ Materials Electronics	♦♦♦ Materials ♦♦ Electronics	♦♦♦♦ Materials ♦♦♦ Electronics	*Japan* ♦♦♦♦ Materials Electronics *ROK, Taiwan* ♦♦ Electronics	♦ Electronics	♦ Electronics	*Switzerland* ♦♦♦ Materials ♦♦ Electronics *Israel* ♦
INTEGRATED SENSORY SCIENCE						
♦♦♦♦ Sensors Lasers	♦♦♦♦ Sensors Lasers	♦♦♦♦ Sensors Lasers	*Japan* ♦♦♦♦ Sensors Lasers *ROK* ♦♦		♦♦♦ Sensors Lasers	*Israel* ♦♦
NONLINEAR OPTICS AND NONLINEAR DYNAMICS						
♦♦♦ CB sensors	♦♦♦ CB sensors	♦♦♦ CB sensors	*Japan* ♦♦♦ Nonlinear materials *China* ♦♦+ Nonlinear materials *Taiwan* ♦♦ Nonlinear materials		♦♦♦	*Israel* ♦♦♦ CB sensors *Australia* ♦♦♦
PHOTONICS						
♦♦♦♦ Signal processing Optical switching OE	♦♦♦♦ Signal processing Optical switching OE Optical computing	♦♦♦♦ Signal processing Optical switching OE	*Japan* ♦♦♦♦ Optical computing Signal processing Optical switching OE *ROK, Taiwan* ♦♦	♦♦–	♦♦♦	*Israel* ♦♦♦♦ Signal processing *Sweden* ♦♦♦ *Australia* ♦♦+
IMAGE ANALYSIS						
♦♦♦♦ Software & modeling	♦♦♦ Software & modeling	♦♦♦ Software & modeling	*Japan* ♦♦♦ Software & modeling *Taiwan* ♦♦		♦♦ Software & modeling	*Sweden, Israel* ♦♦♦ Software & modeling

Note: See page E–6 for legend.

radiation sources and detectors will provide new capabilities for the U.S. Army. Germany, France, the U.K., and Japan have world-class capabilities in the areas of laser application for sensing and other sensor development. Research in this area can contribute to the objectives of the Army STO III.D.16, Integrated Situational Awareness and Targeting.

c *Nonlinear Optics and Nonlinear Dynamics*

Research in optics studies develops optical sensors and sources, nonlinear optical processes, tunable sources, and materials with special reflective, absorptive, and polarization properties to perform specialized remote sensing techniques (e.g., CB agent detection). China is developing better capabilities in the study of nonlinear materials. The U.K., Germany, and France have broad capabilities in the area of CB sensing by optical devices.

d *Photonics*

Photonics is the technology of generating and harnessing light and other forms of radiant energy, the quantum unit of which is the photon. Research seeks to develop optical subsystems for military applications such as information storage, displays, optical switching, signal processing, and optical interconnections of microelectronic systems. The U.K., France, Germany, Japan, and Italy have ongoing research in various photonics areas. Russia has a strong but declining capability in photonics research. Research in obscured visibility seeks to provide the U.S. Army with the ability to operate on the ground in poor visibility and to have significant control of physical signatures. The U.K., France, and Japan have significant capabilities in the related technology areas. Germany, Israel, Sweden, Canada, and Belgium have capabilities that also merit consideration.

Typical research projects in the optoelectronic (OE) area include microwave modulation of diode lasers, optical fiber signal processing, and optical control of microwave and MMW semiconductor devices. There is extensive collaboration with groups in a number of U.K. universities; a European Network is being established.

e *Image Analysis*

The objective of image analysis research is to develop the fundamental limits and theoretical underpinnings of object recognition and image analysis. These areas are of growing importance because of the increasing speed of modern weapons and the need for faster and more accurate identification of friend or foe. It also applies to the development of novel technologies for mine detection, medical imaging, and geophysics. This is an area where a number of countries are developing broad capabilities, including the U.K., France, Germany, and Japan. Israel, Canada, Turkey, and Sweden have important niche capabilities.

f *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in physics:

- Multinational—Nanoscience (Materials) [http://dmxwww.epfl.ch]
- Germany—Max Born Institute for Nonlinear Optics and Short-Pulse Spectroscopy, Rudower Chaussee 6, D–12489 Berlin [http://www.mbi–berlin.de/]
- Australia—Australian Photonics Cooperative Research Centre[http://www.photonics.com.au/tindex.htm]
- Germany—Photonic Optical Interconnection Technology Project, Fraunhofer Institute for Applied Solid-State Physics [http://www.fhg.de/english]
- Japan—Department of Physics, Kyoto University [http://www.scphys.kyoto–u.ac.jp/index–e.html]
- Korea—Photonics Research Center

- Sweden—Chalmers University of Technology and Göteborg University, Photonics, High-Speed Electronics and Nanoscience/Quantum Devices [http://www.chalmers.se/researchprofile/nanoscience.html]
- United Kingdom—The Institute of Microwaves and Photonics, School of Electronic and Electrical Engineering at the University of Leeds [http://www.IMP.leeds.ac.uk/]

4 Chemistry

Basic research in chemistry applies to Army applications such as WMD defense, fuels, and munitions. Chemistry efforts are also strongly tied into interdisciplinary research in advanced materials, physics, and the biological sciences. A large number of international basic research programs in chemistry can contribute to Army goals in this area. International capabilities in chemistry research are summarized in Table E–15.

a *Chemical Detection*

A number of countries are active in materials R&D for chemical detection. The U.K. and Canada have world-class capabilities, and they have ongoing efforts to provide better defense against chemical agents. They have been at the forefront of chemical defense for many years and can be expected to continue devoting resources to this area. Israel, Sweden, Finland, France, Germany, Czech Republic, Poland, China, the Netherlands, and Japan also have some capabilities. Research facilities in surface plasmon resonance systems, redox systems, and field effect transistors are present in Israel, Sweden, and the Netherlands.

b *Power Sources*

Soldier power systems will provide the 21st century warrior with power sources that are enabling for a host of man-portable electronic devices, ranging from communications and sensors to weapons. Where the typical Land Warrior can be expected to require as much as 250 W of power for various subsystems, the warfighter will be a significant component of the future digitized Army. Assimilation of current power technologies into use by the soldier on the battlefield is anticipated for the near future. Lithium rechargeable batteries and fuel cells are expected to become the primary sources of energy. Further, combinations of advanced capacitors with rechargeable batteries make for smart hybrid devices where the battery provides power and is recharged by the capacitor. Batteries with Li chemistries are affordable and environmentally friendly replacements to the nickel cadmium, nickel metal hydride, and Li thionyl chloride (which is environmentally unsafe) rechargeables that are currently used. In particular, Li polymers are very pliable, having the ability to be packaged in most any size and shape. Li batteries are expensive to produce, although continued advances in this chemistry will bring the cost down for improved affordability. Japan is a world leader in the development of Li batteries, while Canada has specific capability in Li polymers. Much of the development in Li batteries stems from powering space vehicles. France and Germany have significant programs in all Li chemistries. Nations such as Israel, China, Russia, and the U.K. demonstrate capability in niche chemistries of the Li family.

A secondary source for near-term soldier power systems are fuel cells. However, because of the irreducible weight of the requisite energy converter, fuel cells are more effective for missions requiring greater than approximately 1 kWhr. The use of PEM fuel cells in equipment has been demonstrated in the battery cavity of a field radio. Fuel cells offer the advantage of significantly reduced thermal and acoustic signatures, with their primary byproduct being water, but are only in the early phases for battlefield usage. Currently, PEM fuel cells demonstrate practical

TABLE E–15. BASIC RESEARCH—CHEMISTRY

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
CHEMICAL DETECTION						
♦♦♦♦	♦♦♦	♦♦♦	*Japan* ♦♦♦ *China* ♦♦♦	♦♦♦	♦♦♦♦	*Australia* ♦♦♦♦ *Israel* ♦♦♦ *Poland, Sweden, Czech Republic, Finland, Netherlands* ♦♦
POWER SOURCES						
♦♦♦ Batteries	♦♦♦♦ Batteries	♦♦♦♦ Batteries Flywheels	*Japan* ♦♦♦♦+ Li Batteries *China* ♦♦	♦♦♦– Flywheels	♦♦♦+ Li Polymers PEMs	*Israel, Italy* ♦♦ Batteries
EXPLOSIVES & PROPELLANTS						
♦♦♦	♦♦	♦♦♦♦	*Japan* ♦♦♦♦ Missile propellants *ROK* ♦♦♦	♦♦♦–	♦♦♦♦	*Sweden, Israel* ♦♦♦♦
ENERGETIC MATERIALS						
♦♦♦♦ Smart munitions	♦♦♦♦ Smart munitions	♦♦♦	*Japan* ♦♦♦ Smart munitions *China* ♦♦♦ *India* ♦♦	♦♦♦	♦♦	*Sweden* ♦♦♦ *Israel, Australia, South Africa* ♦♦
DEMILITARIZATION/ ENVIRONMENTAL REMEDIATION						
♦♦♦♦	♦♦♦	♦♦♦	*Japan* ♦♦ *ROK* ♦♦	♦♦	♦♦ Soil Ground water	

Note: See page E–6 for legend.

applicability for soldier power. Ballard of Vancouver, Canada, is the world leader in this area, with strong global presence by Germany and Japan. Italy demonstrates significant capability, with other European countries following suit.

In the far term, nuclear power and rotating machinery (flywheels) offer further solutions for soldier power. The former has yet to come to practical design due to significant system implementation issues associated with radiation near biological tissue and societal mistrust of ionizing radiation. The specific energy of radioisotopes, however, which can be greater than 100 mW/hr/kg, combined with more efficient energy converters, could easily solve power generation issues for the unmanned future soldier. Continued efforts may also see the development of other power technologies for the infantry (e.g., thermophotovoltaics, biological energy

sources (for milliwatt applications), advanced capacitors and converters). Canada is noted for efforts to develop biomass-derived fuels for gas turbines.

c *Explosives and Propellants*

Basic research is often undertaken to solve problems of explosive/propellant effectiveness or to compile properties sufficient to improve detection or identification. U.S. Army applications include the basic outgassing chemistry for detection of mines and charges. Chemistry used to mimic vehicle IR signatures is applicable to decoy flares. Chemistry of propellant bonding provides insight into the life-cycle projections for U.S. Army missile systems. Germany, with a world-class tradition of expertise in chemistry, leads in most of these areas. U.K. expertise across broad chemistry areas is fertile for international interest. Japan's space interest promotes expertise in missile propellants. Long-term military requirements underscore ongoing basic research in Israel, Singapore, and the ROK. Research in Russia suffers from lack of operating capital.

d *Energetic Materials*

Army interest in energetic materials focuses on energetic compounds made from environmentally friendly synthesis techniques. Over 20 countries have some capability to produce standard energetic materials, such as TNT, RDX, HMX, nitrogen carbon, ammonium perchlorate, metal fuels, hydrazine and compounds, for use in missile, CW/BW, and "smart" munitions applications. The United States, along with France, the U.K., and Japan, maintains a lead in the formulation and production of advanced energetic materials for use in smart munitions. Russia and China have at least researched the synthesis of many of the substances; other countries, including Italy, South Africa, Sweden, Brazil, and Egypt, have a selective capability to produce some of the materials. An increasing number of non-NATO countries have the technology to formulate energetic materials for munitions and weapons applications, their capabilities being limited primarily by the availability of the listed advanced materials and the lack of computational and experimental capability to design and synthesize new molecules and polymers.

e *Demilitarization/Environmental Remediation*

The United States has a strong lead in research related to demilitarization, installation restoration, and pollution prevention. Sensing pollution, destroying pollutants, and practices that prevent pollution all lead to more efficient or more effective military operation. Of foreign countries, the U.K. has the strongest potential. Canada has significant efforts in the chemical characterization of contaminated soil and groundwater. France and Germany have some capability, but the potential for military applications is weaker due to budgetary constraints.

f *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in chemistrky:

- Germany—Max Planck Institute for Colloids and Interfaces [http://www.mpikg–golm.mpg.de/index_e.html]
- Netherlands—Munition Technology and Explosion Safety Division, TNO–PML [http://www.pml.tno.nl/homepage.html]
- South Korea—Environmental Chemical Engineering Laboratory, Seoul National University [http://ecel.snu.ac.kr/]
- Canada—Institute for Integrated Energy Systems [http://www.iesvic.uvic.ca/]

5 Materials Science

Army interests in materials science basic research focus on materials, processes, and properties that improve the performance, increase the reliability, or reduce the cost of Army systems. All industrialized and rapidly developing countries have materials-related activities and capabilities. Many nations can now produce materials for specific military usage, including materials engineered to defeat enemy threats and those that improve the survivability of systems in the field. Table E–16 summarizes international research capabilities in each major research area of materials science.

TABLE E–16. BASIC RESEARCH—MATERIALS SCIENCE

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
MANUFACTURING & PROCESSING OF STRUCTURAL MATERIALS						
♦♦♦♦ Steel, Al, Ti Superalloys Intermetallics Joining PMCs, MMCs	♦♦♦♦ Steel, Al, Ti Superalloys Intermetallics Joining PMCs, MMCs	♦♦♦ Steel, Al, Ti Superalloys Intermetallics Joining PMCs, MMCs	*Japan* ♦♦♦ Steel, Al, Ti Superalloys Intermetallics Joining PMCs, MMCs Ceramics *China* ♦♦♦♦+ Al, Ti Superalloys PMCs, MMCs, CMCs *India* ♦♦ *Vietnam* ♦	♦♦– Al, Ti, steel PMCs, MMCs	♦♦ Steel ♦♦ PMCs ♦♦ Intermetallics	*Austria, Sweden, Israel, South Africa* ♦♦ Steel *Sweden, Spain, Israel* ♦♦ PMCs *Sweden* ♦♦ Superalloys *Sweden* ♦♦ Intermetallics *Israel, Italy* ♦♦ C-C composites *Norway* ♦♦
MATERIALS FOR ARMOR & ANTIARMOR						
♦♦♦♦ Personnel Vehicular Penetrators	♦♦♦♦ Personnel Vehicular Penetrators	♦♦♦♦ Personnel Vehicular Penetrators	*Japan* ♦♦♦ Personnel Vehicular Penetrators	♦♦– Personnel Vehicular Penetrators		*Australia* ♦♦♦ Personnel Vehicular Penetrators *Israel, Slovakia* ♦♦ Armor *Israel, Sweden* ♦♦ Antiarmor *Israel* ♦♦ Personnel

TABLE E–16. BASIC RESEARCH—MATERIALS SCIENCE (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
PROCESSING OF FUNCTIONAL MATERIALS						
♦♦♦ Electrical Magnetic Optical Maintenance Corrosion	♦♦♦ Electrical Magnetic Optical Maintenance Corrosion	♦♦ Electrical Magnetic Optical Maintenance Corrosion	*Japan* ♦♦♦♦ Electrical Magnetic Optical Maintenance Corrosion *China* ♦♦♦♦+ Electrical Magnetic Optical Maintenance Corrosion *India* ♦♦	♦♦– Electrical Magnetic Optical Maintenance Corrosion		*Slovakia, Italy, Netherlands* ♦♦ Electronic & electrical *Norway* ♦♦ Powder metallurgy, casting, metal forming, corrosion silicon MEMS *Netherlands* ♦♦ Magnetic *Netherlands, Israel, Italy* ♦♦ Optical *South Africa* ♦♦♦ Piezoelectric composites
ENGINEERING OF MATERIAL SURFACES						
♦♦♦ Coatings Ion implantation Sputtering Surface resistance to wear & corrosion	♦♦♦ Coatings Ion implantation Sputtering Surface resistance to wear & corrosion	♦♦ Coatings Ion implantation Sputtering Surface resistance to wear & corrosion	*Japan* ♦♦♦ Coatings Ion implantation Sputtering Surface resistance to wear & corrosion *China* ♦♦♦+ Coatings Ion implantation Sputtering Surface resistance to wear & corrosion	♦♦–	♦♦ Coating	*Australia* ♦♦♦+ Coatings Ion implantation Sputtering Surface resistance to wear & corrosion *Switzerland, Sweden, Netherlands, Italy* ♦♦ Coatings *Italy, Sweden, Netherlands, Switzerland* ♦♦ Machining Finishing Ppolishing *South Africa, Israel* ♦♦ Diamond deposition

TABLE E–16. BASIC RESEARCH—MATERIALS SCIENCE (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
NONDESTRUCTIVE CHARACTERIZATION OF COMPONENTS						
♦♦♦ Metrology Systems MRI	♦♦♦ Metrology Systems MRI	♦♦ Metrology Systems MRI	*Japan* ♦♦♦ Metrology Systems MRI *China* ♦♦+ Metrology Systems MRI	♦♦– Metrology Systems MRI	♦♦– Metrology Systems MRI	*Sweden, Switzerland* ♦♦ Metrology *Italy, Sweden* ♦♦ NDE

Note: See page E–6 for legend.

a *Manufacturing and Processing of Structural Materials*

Processing of materials is critical to Army interests. It ranges from synthesis of precursor materials through microstructural developments and into production of useful components at acceptable costs. Materials processing includes such topics as polymerization, composite lay-up, physical and chemical vapor deposition, and surface modifications.

Many nations have significant capability in the manufacturing and processing of advanced materials of interest to the Army. The U.K., France, Germany, and Japan are at or near the forefront of research into the processing of steels, titanium, aluminum, PMCs, MMCs, superalloys, intermetallics, and C-C composites. Expertise in these areas also resides in the FSU, especially Russia. Niche capabilities can be found in many other countries (e.g., advanced steel research in Austria, Sweden, Canada, and South Africa; C-C composite expertise in Israel and Italy). Growing capabilities are developing in Asia and the Pacific Rim, particularly in China, India, and South Korea.

Smart materials are those that can sustain sensory capabilities, actuator activity, and information processing as part of their basic microstructure. Design, synthesis, and processing of such materials is a chemical challenge because it is done at the atomic/molecular level. Applications such as damage detection and control, vibration damping, and precision manipulation and control motivate the field. At the microstructural level, challenging areas of interest include phase transitions (e.g., SMAs), layer-by-layer design of materials, materials with defective structures that can sustain sensing and response, biocomposites, piezoelectric ceramics, multifunctional macromolecules, and others. This area offers large payoffs in areas such as delamination control of composite helicopter blades and increased battlefield survivability of materials by means of active damage control. World activity in smart materials continues to grow rapidly. Japan is a clear leader in some aspects. France, Germany, and South Korea also have growing programs.

Japan also has strong capabilities in virtually every area of the underlying materials technology related to ceramics. The ceramics R&D program is heavily funded and increasingly coordinated at the highest levels (MITI). It involves a large infrastructure of government laboratories, universities, and private industry. The pervasive commercial potential of ceramics has led Japan to make it one of their continuing high-priority items. The Japan Fine Ceramics Center in Nagoya, founded in 1987, institutionalized ceramic R&D in Japan. Its aim is to extend Japan's already considerable capability in both precompetitive "basic" research by consortia and in sophisticated proprietary research up to a pilot plant level. The central role of the Japan Fine Ceramics

Center as the setter of standards and IPOCs makes it an ideal point of entry to the Japanese ceramics infrastructure at large.

b *Materials for Armor and Antiarmor*

Armor materials include those specifically designed to protect equipment and personnel from enemy threats. Antiarmor materials are used in the projectiles, penetrators, shaped-charge liners, etc., designed to defeat enemy armor. For armor, the U.K., France, Germany, Israel, and Russia are overall world leaders; the United States is the leader in developing antiarmor projectile materials. The U.K., France, Israel, Sweden, and Russia have very significant and relevant dense alloy capabilities.

Thick-sectioned, glass-reinforced PMCs are of interest to the Army because they offer weight savings while providing to other systems useful, stringent characteristics, with controlled costs. Among these characteristics are ballistic protection for personnel, equipment, emplacements, and vehicles. Most overseas work, done in the commercial sector, is focused on manufacturing and processing issues. The U.K., France, Canada, Germany, and Japan have broad capabilities and research in PMCs. Israel, Spain, and South Korea have important and growing capabilities.

c *Processing of Functional Materials*

Processing of functional materials is key to deriving military advantage from specialized optical, magnetic, electrical, and electronic devices. Optical systems of interest include waveguides, lenses, mirrors, laser hosts, and sensor covers. For magnetic materials, the Army is concerned with data recording media, signature control, power supplies, and motor applications. For electrical materials, the focus is on solenoids, minesweeping, and high-field magnets. Electronic materials are the foundation of the Army's electronic systems, so they are of interest for logic, amplification, memory, display, delay, signal generation, sensing, and switching functions.

For processing of functional materials, the United States generally has led overall, but others (France, the U.K., Germany, Japan, Switzerland, and Russia) have strong capabilities. Japan is more advanced than the United States in some areas of electronic materials. The U.K., Russia, Japan, Israel, Germany, France, and China are very active across several areas of optical materials. For magnetic materials, the United States is the leader overall, although Japan has some capabilities. The U.K. is capable in high-permeability magnetic alloys. For magnetorestrictive alloys, Sweden and the U.K. have technologies comparable to those of the United States. Many other nations are active in selected areas of magnetic materials. For electrical materials, the United States has the lead in superconducting wire. Japan, Germany, Italy, and the U.K. have capabilities in wire processing. High-temperature superconducting materials work is performed globally, with the United States in the lead with prototype wire processing.

The processing of nonlinear optic materials is important to the Army because of the materials use in wavelength conversion in some laser systems and in personnel eye protection. The materials must be very uniform and of some high purity; the selection of useful materials currently is limited. The U.K., France, and Russia have strong efforts in preparation and characterization of nonlinear optic materials, and Japan and Israel have credible capabilities. Hungary and China are also working extensively in this area.

Fire-retarding materials for vehicles are of significance to the Army to protect personnel from conflagrations and to allow assets to return to operation as rapidly as possible. These materials

are essential to enabling Army systems to perform under battlefield conditions. This capability allows for sustainability of vehicles involved in force projection and advanced land combat. In addition to being fire retardant, these materials must be easily applied to vehicles and not produce toxic products when exposed to high temperatures. The countries with strong capabilities in these areas are the U.K., France, and Israel.

d *Engineering of Material Surfaces*

Precise control, fabrication, and modification of materials' surfaces are areas with great impact on Army systems. The surface is the region where the component meets its operating environment, which may be chemical, mechanical, thermal, EM, etc., in nature. It is the region within which failure usually originates during system performance or storage. Thus, activity in areas including machining, ion implantation, chemical vapor deposition, sputtering for coatings, and adhesion of protective layers are of interest in the engineering of surfaces for Army applications.

Materials' surface engineering capabilities are widely held across the world. For precision machining and polishing, Japan, Germany, France, and the U.K. are very strong, along with Switzerland and Sweden. For coatings of many types, France, Germany, the U.K., and Russia are among the leaders. Areas of strength exist abroad in ion implantation and thin-film diamond deposition in France, Japan, Germany, and the U.K.

Wear and corrosion costs the Army several billion dollars each year because of premature failures, excessive wear of systems and components, application and removal of protective coatings and paints, and need to have high spares inventories to meet all these challenges. Corrosion control and avoidance is a challenging scientific area, as is tribology (the study of surfaces in contact). These areas are exceptionally important for maintainability and affordability, in terms of life-cycle costs, for Army systems. Nearly all industrialized nations have programs of some extent in wear and corrosion. The strongest are in the U.K., Germany, Japan, France, Sweden, and Switzerland, with niche capabilities existing elsewhere.

e *Nondestructive Characterization of Components*

Nondestructive evaluation of components divides into a few focus areas. For quality of materials produced, France, Germany, the U.K., other European nations, and Japan have increased capabilities with NDE systems. In all aspects of metrology, Japan is excellent, as are the U.K., France, and Germany. Switzerland and Sweden also excel in selected areas. All of these nations are paying growing attention to automation in the use and interpretation of NDE, both for product quality and process control.

f *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in materials science:

- Netherlands/Italy—Institute for Advanced Materials, Joint Research Center [http://www.ehis.navy.mil:80/ bwnews19.htm] [http://www.jrc.nl]
- Israel—Israel Institute of Metals, Technion Research and Development Foundation http://www.ehis.navy.mil:80/ bwnews20.htm] [http://www.technion.ac.il/technion/trdf/metal/]
- India—Indian Institute of Science, Department of Metallurgy [http://www.metalrg.iisc.ernet.in/]
- Vietnam—The Institute of Materials Science [http://www.atip.org/public/atip.reports.99/atip99.001.html]

6 Electronics Research

Basic research in electronics supports advanced technology development with many applications. Important examples include continued advancement in solid-state devices, telecommunications, microwave and MMW circuit integration, image analysis, and low-power electronics. Table E–17 shows that many countries host capabilities that support military applications and a wide range of civil applications.

TABLE E–17. BASIC RESEARCH—ELECTRONICS RESEARCH

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
			SOLID-STATE & OPTICAL ELECTRONICS			
♦♦♦ MEDEA Semiconductors	♦♦♦♦ MEDEA, LETI, LIMMS Semiconductor device s	♦♦♦♦ MEDEA Semiconductors	*Japan* ♦♦♦♦ LIMMS, ASET Solid-state research Integrated optics *ROK* ♦♦ Solid-state research	♦♦		*Belgium* ♦♦ OE *Ireland* ♦♦ Solid-state & optical electronics
			INFORMATION ELECTRONICS			
♦♦♦ General telecommunications Various antennas Digitized battlefield	♦♦♦ General telecommunications Battlefield communications	♦♦♦ General telecommunications Heterogeneous networks	*Japan* ♦♦♦ Most phases of telecommunications (both fiber & wireless) *ROK, Singapore* ♦♦ General telecommunications	♦♦		*Netherlands* ♦♦♦ Digitized battlefield *Sweden, Finland* ♦♦♦ General telecommunications *Austria* ♦ Information fusing
			ELECTROMAGNETICS			
♦♦♦♦ Terahertz technology Quasi-optics Microwave tubes Antennas	♦♦♦♦ Terahertz technology Microwave tubes Antennas ASET Magnetic storage	♦♦♦♦ MMW technology Microwave tubes Antennas	*Japan* ♦♦♦ Terahertz technology Acoustic wave devices Microwave tubes Antennas	♦♦	♦♦ Microwave tubes Antennas	*Spain* ♦ Quasi-optic waveguides

Note: See page E–6 for legend.

a *Solid-State and Optical Electronics*

This area of research concentrates on the development of advanced semiconductor devices, advanced millimeter and submillimeter systems, and short-wavelength lasers. Basic research is directed at ultra-fast devices, devices operating at lower power levels, and OE devices. Japan and a number of European countries are active in these areas. For example, the U.K. is noted for research in the synthesis of novel phosphor materials. Researchers in Italy are collaborating with the Army on understanding breakdown mechanisms in heterojunction devices.

In Japan, ASET, a research partnership of 35 Japanese, 4 foreign affiliate companies, and 1 foreign company, conducts a very large effort. ASET's projects are in the fields of silicon large-scale integration technology, magnetic storage, and EO display technology. Much of the effort in

Europe operates under the umbrella of the Microelectronic Development for European Applications (MEDEA), with a goal of developing new semiconductor process technologies. Specific organizations involved in these or similar studies are SGS–Thomson (France), Fraunhofer Institute for Applied Solid-State Physics (Germany), and LETI (France).

In OE, the University of Ghent (Belgium) is active in photonic integrated circuits and optical coupling; the University College (U.K.), the University of Duisberg (Germany), and Thomson (France) are active in microwave photonics; and Toshiba, Fujitsu, and NEC (Japan) are active in short-wavelength lasers.

b *Information Electronics*

Research in most phases of information electronics is worldwide. Digitization of the battlefield is a research concept at TNO–FEL (Netherlands) and DERA (U.K.). Research programs in active antennas are underway at Ministry of Posts and Telecommunications (Japan), Dornier Satellite Systems and University of Karlsruhe (Germany), TNO–FEL (Netherlands), University of Bradford (U.K.), and Alcatel (France).

c *Electromagnetics*

Terahertz research is quite widespread. Among the organizations active in this technology are the University of St. Andrews (Scotland), University of Urlangen (Germany), and the Research Institute for Electrical Communication/Mizuno Laboratory (Japan). Research organizations actively pursuing work in various phases of microwave equipment (e.g., microwave antennas, waveguides, tubes) include the Universidad Publica de Navarra (Spain), Microwave and Antenna Systems (U.K.), and CNRS (France).

d *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in electronics research:

- Japan—ASET (Lithography) [http://www.aset.or.jp/r_index1–e.html]
- Korea—Opto-Electronics Research Center
- France—LETI (and its subsidiary GRESSI) [http://www-dta.cea.fr/home_leti–uk.htm]
- Netherlands—TNO–FEL [http://www.tno.nl/]

7 Mechanical Sciences

The field of mechanical sciences is divided into the areas of structures and dynamics, solid mechanics, fluid dynamics, and combustion and propulsion. Structures and dynamics encompasses the disciplines of structural dynamics, M&S, and air vehicle dynamics. These areas are crucial for weapon platform stability, weapon lethality, and smart weapon development. Solid mechanics includes topics relating to the mechanical behavior of materials, the integrity and reliability of structures, and tribology. These topics are important for damage propagation and control, weapon penetration mechanics, and platform life prediction. The priority areas within fluid mechanics include unsteady aerodynamics, aeroacoustics, and vortex-dominated flows. These areas help provide a better understanding of the phenomenon associated with projectile behavior, blast patterns, and chemical dispersion. Combustion and propulsion covers research in small gas turbine propulsion, reciprocating engine propulsion, and novel gun propulsion technology. These research fields contribute to efficient turbomachinery components, enhanced

engine air utilization, and novel ignition mechanisms. Table E–18 summarizes international research capabilities in each major research area of mechanical sciences.

TABLE E–18. BASIC RESEARCH—MECHANICAL SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
STRUCTURES & DYNAMICS						
♦♦♦♦ Smart/active structures M&S Structural acoustics	♦♦♦♦ Smart/active structures M&S	♦♦♦♦ Smart/active structures M&S	*Japan* ♦♦♦♦ Smart/active structures M&S *ROK* ♦♦♦♦ Smart/active structures *India, China* ♦♦♦ Smart/active structures M&S	♦♦♦ Smart/active structures M&S		*Italy* ♦♦♦♦ Smart/active structures M&S *Brazil, Israel, South Africa, Poland* ♦♦♦ Smart/active structures
SOLID MECHANICS						
♦♦♦♦ Material behavior Structure reliability	♦♦♦♦ Material behavior Structure reliability	♦♦♦♦ Material behavior Structure reliability	*Japan* ♦♦♦♦ Structure reliability ♦♦♦ Material behavior *China, India, ROK* ♦♦♦ Material behavior Structure reliability	♦♦♦ Structure reliability ♦♦ Material behavior		*Italy, Spain, Israel* ♦♦♦ Material behavior Structure reliability *South Africa, Turkey, Sweden, Norway, Slovenia, Denmark, Australia* ♦♦ Material behavior Structure reliability
FLUID DYNAMICS						
♦♦♦♦ CFD, theoretical ♦♦♦ Experimental	♦♦♦♦ CFD, theoretical ♦♦♦ Experimental	♦♦♦♦ CFD, theoretical ♦♦ Experimental	*Japan* ♦♦♦♦ CFD, theoretical ♦♦ Experimental *India* ♦♦ CFD, theoretical	♦♦ CFD, theoretical	♦♦♦♦ CFD, theoretical	*Belgium* ♦♦♦♦ CFD, theoretical *Italy* ♦♦♦+ CFD, theoretical *Netherlands, Sweden, Australia* ♦♦♦ CFD, theoretical

TABLE E–18. BASIC RESEARCH—MECHANICAL SCIENCES (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
COMBUSTION & PROPULSION						
♦♦♦♦ Small gas turbine Reciprocating engines Solid/liquid gun	♦♦♦♦ Small gas turbine Solid/liquid gun ♦♦ Reciprocating engines	♦♦♦♦+ Reciprocating engines; solid gun; Small gas turbine	*Japan* ♦♦♦♦ Reciprocating engines ♦♦♦ Solid/liquid gun Small gas turbine *ROK* ♦♦♦ Reciprocating engine *ROK, India* ♦♦ Solid gun	♦♦♦♦ Novel gun propulsion ♦♦♦ Small gas turbine Reciprocating engine	♦♦♦♦ Solid gun Reciprocating engines Small gas turbine	*Finland* ♦♦♦ Reciprocating engines *South Africa* ♦♦♦ Solid gun *Netherlands, Switzerland, Italy* ♦♦ Small gas turbine *Australia* ♦♦♦♦ Solid gun Reciprocating engines Small gas turbine

Note: See page E–6 for legend.

a *Structures and Dynamics*

The area of structures and dynamics consists of structural dynamics, M&S, and air vehicle dynamics. Within structural dynamics, the highest priority research is in ground vehicle and multibody dynamics, structural dampening, and smart structures. Achieving the goal of significant vibration reduction in Army vehicles will result in substantial increases in weapon platform stability, weapon system reliability, weapon lethality, and crew performance. Within air vehicle dynamics, there is priority research in integrated aeromechanics analysis, rotorcraft numerical analysis, helicopter blade loads and dynamics, and projectile elasticity.

The U.K., Germany, Italy, France, and Japan all demonstrate world-class capabilities in smart/active structures. South Korea has made notable progress and should be recognized as having similar world-class capabilities. In addition, India, China, Brazil, Israel, South Africa, Poland, Turkey, Russia, and Ukraine all demonstrate potential future applications in the same area. The U.K. continues to be the foreign leader in R&D concerning structural acoustics.

b *Solid Mechanics*

In the area of solid mechanics, the research topic areas are the mechanical behavior of materials, the integrity and reliability of structures, and tribology. The classes of materials of interest are functional gradient materials and heterogeneous materials. Within mechanical behavior, the primary research thrusts are material responses in the state of nonequilibrium or in transient states—as in impact and penetration mechanics—and damage initiation/propagation. In addition, the mechanical response under coupled effects of electric, magnetic, and thermal fields is of great interest. Research in the area of integrity and reliability of structures focuses on damage tolerance, damage control, and life prediction. In the area of tribology, dynamic friction, lubrication, and surface topology in low-heat-rejection environments are emphasized.

For the solid dynamics area, the U.K., France, and Germany all exhibit world-class capabilities in the area of mechanical behavior of materials. Japan, Italy, Spain, and Israel all show some

world-class capabilities. India, South Korea, China, Norway, Slovenia, Sweden, Denmark, South Africa, Turkey, and Australia show capabilities in a few points of material behavior. In the research area of structural reliability, the U.K., France, Germany, and Japan have world-class capabilities. Italy, Spain, and Israel exhibit several areas of strength in the field. South Africa, Turkey, Australia, Norway, Slovenia, Sweden, Denmark, China, India, and South Korea have a few well-developed capabilities. Russia and Ukraine have the resources to develop excellent capabilities in all areas of solid dynamics, but do not currently have world-class capabilities.

c *Fluid Dynamics*

Research in fluid dynamics can provide a better understanding of the phenomenon associated with projectile behavior, blast patterns, and chemical dispersion. Future advances would enhance the ability to predict the capabilities of smart munitions, integrated propulsion systems, flight dynamics, G&C systems, and CB threat behavior. Fluid dynamics research priority areas are unsteady aerodynamics, aeroacoustics, and vortex-dominated flows. Complementary research using CFD for multibody aerodynamics would provide the capability to predict and define submunition dispensing systems. Multidisciplinary research in this area will lead to hypervelocity launch technology and to low-speed military delivery systems.

Through the increasing use of commercially available CFD codes, the EC is quickly coming up to speed in the area of computational M&S. The U.K., France, and Germany continue to have a strong hold in this area, while many of their neighbors, including Belgium, the Netherlands, and Sweden, show great potential. Studies in the U.K., France, and Japan have contributed significantly to missile, rotor, and explosive design. Continued lack of support in Russia and the Ukraine, however, has led to their lack of increasing capabilities. The experimental aspect of fluid dynamics has taken secondary priority to the advancement of increasingly powerful CFD techniques. Despite this trend, the U.K., Germany, France, and Japan have maintained mature capabilities in this area.

d *Combustion and Propulsion*

Combustion and propulsion research supports advanced technology development in small, gas turbine engine propulsion; reciprocating engine propulsion; and solid, liquid, and novel gun propulsion technology. The development of high-performance, small, gas turbine engines requires basic research in turbomachinery stall and surge, as well as advances in CFD simulation. These basic research areas directly contribute to highly loaded, efficient turbomachinery components. Reciprocating engine technology research tends to move forward at a more evolutionary pace, with advances in ultra-low heat rejection, enhanced air utilization, and cold-start phenomena as priority areas. Solid gun propulsion technology requires research priorities to be placed on ignition and combustion dynamics and high-performance, solid-propellant charge concepts. Liquid gun propulsion requires priority research in atomization and spray combustion; ignition and combustion mechanisms; and combustion instability, hazards, and vulnerability. Novel gun propulsion depends on ECT propulsion, active control mechanisms, and novel ignition mechanisms.

In the combustion and propulsion area, the U.K., Germany, and France demonstrate world-class capabilities in small, gas turbine engine development. Germany in particular seems to be improving in small-scale gas turbine research. Canada, Australia, Russia, and Japan approach this level of capability in limited areas, but show good potential over the next decade to make significant contributions to small, gas turbine power-to-weight ratio improvement. The Nether-

lands, Switzerland, and Italy have capabilities in a few areas of gas turbine work. Germany leads in reciprocating engine development technology, with Japan also demonstrating world-class capability. Both countries excel particularly in the application of ceramic materials to low-heat-rejection technology. The U.K. also demonstrates excellent reciprocating engine development capability, with France, Canada, Australia, Finland, and South Korea exhibiting good future potential. Russia and Ukraine have demonstrated mature research in the past, but limited resources are causing a decline in future potential. Novel gun propulsion technology leadership is still maintained by Russia, but its future growth potential may be limited. The U.K. leads in the field of liquid gun propulsion development technology, with Japan showing significant potential. Solid gun propulsion development technology is improving in a number of countries, including the U.K., France, Germany, Canada, and Australia. Japan and South Africa demonstrate significant future potential.

e *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in mechanical sciences:

- Korea—Pohang University of Science and Technology, Smart Structures Laboratory [http://www.postech.ac.kr/e/research/centers.html]
- Japan—Engineering Research Association for a Supersonic/Hypersonic Transport Propulsion System Project [http://www.kansai–ri.co.jp/]
- Canada—Intelligent Sensing for Innovative Structures [http://www.isisCanada.com]
- United Kingdom—Association for Structural and Multidisciplinary Optimization in the United Kingdom [http://www.brad.ac.uk/staff/vtoropov/asmo_uk/index.html]

8 Atmospheric Sciences

Weather and climate are major factors that can affect any operation. A thorough knowledge of and ability to predict patterns and phenomena, and adapt to them are therefore of keen interest to the U.S. Army. To maintain superiority on the battlefield, an all-weather capability must exist and be exploited to eliminate environmental factors as an element. Prediction and foreknowledge of the environment thus improves chances for uninterrupted communication and transportation. Three major research areas are of interest to the Army in atmospheric sciences: atmospheric effects on sensors and systems, characterization of the atmospheric boundary layer at high resolution, and management of atmospheric information.

During this decade, information technology has exploded, increasing capabilities in remote sensing and other similar fields. This has made data sets available at a faster rate worldwide, spawning greater research in areas of meteorology and solar and terrestrial physics, for example. Remote sensing is of great importance to the Army as the detection of weather phenomena and objects, manmade or natural, is simplified. Most European and Asian countries that were not as actively involved beforehand now have their own programs and participate in international programs such as the World Meteorological Organization (WMO) [http://www.wmo.ch] and in numerous conferences. As a result, the base technical capability required to be a global contributor in the area of atmospheric sciences has risen.

A continual burden to Russia's technical capability is a lack of financial resources. Russia maintains high standards of scientific excellence through its large number of scientific institutions; however, aging equipment and the erosion of many programs are preventing them from leading

state-of-the-art programs. Japan represents the strongest Asian technical presence, with its Asian neighbors demonstrating competence and a growing desire for international collaboration. Several European countries have world-class programs, with the U.K., Germany, and France, regarded as the European leaders. Table E–19 depicts the international capabilities in atmospheric science research.

TABLE E–19. BASIC RESEARCH—ATMOSPHERIC SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
ATMOSPHERIC EFFECTS ON SENSORS & SYSTEMS						
♦♦♦♦ Dynamic processes	♦♦♦ ISTP	♦♦♦ Acoustic propagation	*Japan* ♦♦♦ ISTP *China, Taiwan* ♦	♦♦♦ Dynamic processes	♦♦♦ Adaptive optics	*Australia, Israel, Norway* ♦ *Denmark, Italy Finland, Netherlands* ♦♦
CHARACTERIZATION OF THE ATMOSPHERIC BOUNDARY LAYER AT HIGH RESOLUTION						
♦♦♦♦ Remote sensing	♦♦♦ All	♦♦♦♦ Aerosols	*Japan* ♦♦♦♦ Remote Sensing	♦♦♦	♦♦♦♦	*Australia, Israel, Norway, Spain* ♦ *Denmark, Finland, Netherlands* ♦♦ *Italy* ♦♦♦
MANAGEMENT OF ATMOSPHERIC INFORMATION						
♦♦♦♦ Visualization	♦♦♦ Modeling	♦♦♦ Modeling	*Japan* ♦♦♦♦ HPC	♦	♦♦♦	*Australia, Denmark, Finland, Norway* ♦ *Israel, Sweden, Netherlands* ♦♦

Note: See page E–6 for legend.

a *Atmospheric Effects on Sensors and Systems*

The propagation of signals is subject to scattering and attenuation because of varying indices of refraction and an abundance of charged particles in the environment. From source to target, acoustic and EM transmissions can be scattered from changes in the medium, where propagation behavior is path dependent. Further, small-scale atmospheric turbulence and scintillation can cause significant attenuation and scattering of a transmitted signal. Transmission of not only signals, but aerosols or other agents, is of crucial importance due to the CB weapons threat. Modeling and prediction of these events are therefore of interest to the Army to achieve its mission with maximum effectiveness. Several groups are performing research in the area of propagation research.

Sampling of small-scale atmospheric turbulence has been used in ground-based astronomy through adaptive optics. Here, a laser is used to excite a "guide star" in the thin sodium layer about the atmosphere. The guide star, fluoresced adjacent to the intended star, samples local turbulence and deforms a focusing mirror to counter its effects on the incoming star's visible light. The result is an image taken without the effects of atmospheric turbulence. This technique, used

in the airborne laser, can be used in other Army applications. Adaptive optics are found on many ground-based telescopes and in other optical devices.

Many atmospheric studies focus on the propagation of pollutants and various environmentally damaging particles. The International Solar-Terrestrial Physics (ISTP) program, however, is a major international collaboration of ground- and space-based measurements led by NASA, the European Space Agency, and the Institute of Space and Astronautical Science (Japan). One of the goals of the ISTP is to develop the first solar-terrestrial model that predicts atmospheric events as they are influenced by solar disturbances. The ionosphere (and magnetosphere) plays a big role because of the susceptibility of EM fields and sensors to extremes in solar weather.

b *Characterization of the Atmospheric Boundary Layer at High Resolution*

The atmospheric boundary layer, an interface of approximately 1 km between the Earth's surface and the troposphere, is subject to daytime heating and nighttime cooling. These thermal changes taking place over heterogeneous terrain can cause of considerable weather variations over small temporal and spatial scales. How these variations couple the boundary layer over land to that over water is a mechanism for study as well. Real-world simulations of wind vectors, temperature, and moisture are key to weather prediction and tracking the dispersion of aerosols and other agents.

The European Experiment on Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere Over Europe (EUROTRAC–2) comprises 250 research groups in approximately 30 countries. In particular, the Global and Regional Atmospheric Modeling (GLOREAM) experiment could be of significant interest to the Army. Much work is going into atmospheric modeling and tropospheric chemistry. For example, the High-Resolution Limited Area Model (HIRLAM) project is an international effort to develop a numerical, short-range weather forecasting system that analyzes surface pressure, atmospheric temperature, wind velocity, and humidity. Meteorological institutes in Denmark, Finland, Iceland, Ireland, the Netherlands, Norway, Spain, and Sweden are participants and cooperate with Météo–France. A great majority of work is being driven by environmental concerns and the effects on weather of air pollution and smog, ozone depletion, ocean circulation, and global warming.

c *Management of Atmospheric Information*

Information is meaningless unless it can be presented efficiently and interpreted by the user. Visualization and display of information, as well as delivery to the soldier and decisionmaker, are critical to all aspects of the atmospheric sciences effort. An additional top priority is capability in high-performance computational techniques that combine direct and indirect measurements into a forecast model or real-world battlefield visualization. Because weather prediction is a probabilistic science, error assessment can substantially influence the decisionmaking process. Areas of interest include imaging techniques, signal processing, and modeling for multivariate data.

Management of atmospheric information can generally be as sophisticated as the meteorological programs themselves. In other words, with larger and increased numbers of datasets comes the need for more efficient ways of storing, delivering, and displaying the data. The majority of visualization research is performed at the university level with significant international collaboration and visitor exchange.

d *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunies in atmospheric sciences:

- Switzerland—WMO, Geneva [http://www.wmo.ch/]
- EUROTRAC [http://www.gsf.de/eurotrac/et–2.htm]
- United Kingdom—Applied Optics Group, Blackett Lab, Imperial College [http://op.ph.ic.ac.uk/]

9 Terrestrial Sciences

Basic research in terrestrial sciences studies terrain characteristics and processes, including topography, climatology, and hydrology. This research critically affects all aspects of mission planning, logistics, unit effectiveness, and system performance. Knowledge of the topographical, geological, climatological, and hydrological characteristics of the landscape is critical to mobility/countermobility, logistics, communications, survivability, and troop and weapon effectiveness. The digital battlefield also requires detailed and sophisticated information about topography, as well as terrain and environmental features and conditions. Of particular importance to Army goals is terrestrial science research in three broad areas: terrain characterization and analyses, hydrodynamic and surficial processes, and geotechnical engineering. Table E–20 highlights international research capabilities in terrestrial sciences.

TABLE E–20. BASIC RESEARCH—TERRESTRIAL SCIENCES

Technology	United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
TERRAIN PROPERTIES & CHARACTERIZATION							
	♦♦♦♦	♦♦♦♦+ Remote sensing	♦♦♦♦ Remote sensing GIS	*Japan* ♦♦♦ *China* ♦♦	♦♦	♦♦♦	*Netherlands* ♦♦♦+ *Sweden, Australia* ♦♦♦
TERRESTRIAL PROCESSES & LANDSCAPE DYNAMICS							
	♦♦♦♦	♦♦♦	♦♦♦	*Japan* ♦♦♦ *India, China* ♦♦	♦♦	♦♦♦♦	*Netherlands* ♦♦♦+ *Australia, Israel* ♦♦♦
TERRESTRIAL SYSTEM MODELING & MODEL INTEGRATION							
	♦♦♦♦	♦♦♦	♦♦♦+	*Japan* ♦♦♦ *China* ♦♦	♦♦–	♦♦♦+	*Sweden, Norway* ♦♦♦

Note: See page E–6 for legend.

International capabilities in these areas of research related to Army goals include studies of hydrogeology in Israel and Canada and magnetohydrodynamics and hydrology work in France and the U.K. Other countries with active basic research programs include Japan, Australia, India, China, Russia, and the Netherlands.

a *Terrain Properties and Characterization*

This field contributes to the characterization of the surface geometry and terrain features needed for enhanced planning and tactical decisionmaking, as well as designing equipment adaptable to the varied natural environment. Research on topography and terrain seeks to develop new remote sensing data acquisition capabilities and data synthesis and analysis techniques to develop topography and terrain database information. This work is supported by studies of the dynamical physical processes involved in the interactions between surface features and materials and the atmospheric boundary layer and weather systems in order to produce highly sophisticated models of dynamic environmental effects on mission performance. Countries with active research in this area include Australia, Sweden, France, Germany, China, and the Netherlands.

b *Terrestrial Processes and Landscape Dynamics*

Basic research in hydrodynamics relates to the hydrologic cycle and focuses on hydrometeorology, rainfall/runoff dynamics, and fluvial hydraulics, as well as the relationship between surface and groundwater hydrology. Research in surficial processes relates to the geomorphological character of the surficial environment, primarily the physical processes operating in arid/semiarid, tropical, and coastal environments. This work contributes to the ability to estimate hydrologic/physical response and therefore to the ability to accomplish specific activities within a range of expected environmental conditions.

c *Terrestrial System Modeling and Model Integration*

Research in this field focuses on the strength and behavior of materials under a variety of external forces, both natural and manmade. This includes studies of the properties of snow, ice, and frozen ground, as well as soil dynamics and structural mechanics. International capabilities in areas related to Army goals include research on retrofit material systems in the U.K., geotechnical materials research in France, and precision experiments in structural response in Germany. The Scandinavian countries, most notably Norway and Sweden, have made advances in soil mechanics and land use planning, respectively. Many other countries have significant capabilities in niche areas of geotechnical engineering, including Japan (earthquake engineering), India, Canada, and China.

d *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in terrestrial sciences:

- Australia—Australian Geodynamics Cooperative Research Center [http://www.agcrc.csiro.au/]
- Austria—International Symposium on Acoustic Remote Sensing [http://www.boku.ac.at/imp/isars/]
- The Netherlands—Vrije Universiteit Amsterdam [http://www.geo.vu.nl/users/hydro/index.html]
- Canada—National Water Research Institute [http://www.cciw.ca/nwri/]
- Russia—Hydrometeorlogical Centre of Russia

10 Biomedical Research

Basic research efforts in the biomedical sciences related to military missions address four areas: infectious diseases of military significance, combat casualty care, Army operational medicine, and medical CBD (MCBD). The first relates to protection/prophylaxis of personnel deployed to

a mission area from indigenous organisms or to biological agents; the second, to care of personnel following acute injury; the third, to enhancers/sustainers of performance in the field; and the fourth, to treatment and care of persons following exposure to biological agents. These areas of investigation are dual use and affect general health care delivery, although military aspects often differ from civil concerns in several critical instances. For example, deployed military personnel may be more susceptible than indigenous populations to infectious agents because of a lack of prior exposure. Also, developing novel means useful in delaying onset of clinical disease in the face of the physically and mentally demanding nature of combat is of critical importance, because incapacitating military forces for short periods may have profound effects on the outcome of operations. Table E–21 summarizes international capabilities in medical research.

a *Infectious Diseases of Military Importance*

Basic research in infectious diseases of military significance concentrates on the prevention, diagnosis, and treatment of infectious diseases affecting readiness and deployment. The human genome effort will identify those gene profiles that render specific populations more susceptible to disease than other populations. The entire human genome is anticipated to be characterized in 2003, and perhaps sooner.

The human genome project is a multinational effort spearheaded by the United States, the EC, and Japan; the information is freely available on the Internet. Novel combinatorial chemistry strategies have allowed the synthesis of nonpeptide molecules that bind gene fragments, receptors, or cell proteins and thereby offer the potential of protection against threat agents. These same materials also may provide utility in multiarray sensors used for the detection of biological agents. Combinatorial chemistry strategies are being pursued in many developed nations through the pharmaceutical sector. Switzerland, Sweden, and Israel have expertise in these areas, as do the above-mentioned nations. Although China does have a capability in production of several antibiotics, much of the technology is obtained through license of foreign technologies. There are innovative joint research efforts between China and several U.S. firms; however, current Chinese capability in antibiotic and vaccine development and production more closely approximates that of developing nations with extensive foreign investment.

b *Medical Chemical and Biological Defense*

Foreign efforts in medical chemical defense closely parallel those in medical biological defense. For the most part, countries that are engaged in one are also active in the other. The one exception to the countries listed is the Netherlands. The Dutch effort in medical chemical defense is not as extensive as in medical biological defense. All countries listed have world-leading capabilities and none is expected to pull ahead of the others.

Normally occurring biomolecules that enhance or degrade the immune response of persons to infectious materials or to toxins have now been identified. These materials are called biological response modifiers. Treatment with novel biological response modifiers of military forces who may have been exposed to pathogenic agents as a consequence of deployment or through biological agent attack may enhance the survival or sustain the performance of the affected personnel. In the past few years, it has been shown that transport of infectious materials across cell membranes is a critical element in viral replication and maturation. Chemical treatment that interferes with the ability of a virus to bind to a target cell or with intracellular transport can impede viral multiplication and infectivity. Such treatments may sustain performance of

TABLE E–21. BASIC RESEARCH—BIOMEDICAL RESEARCH

<table>
<tr><th>United Kingdom</th><th>France</th><th>Germany</th><th>Japan/Asia</th><th>Russia</th><th>Canada</th><th>Other Countries</th></tr>
<tr><td colspan="7">INFECTIOUS DISEASES OF MILITARY IMPORTANCE</td></tr>
<tr>
<td>♦♦♦♦
Human genome & disease susceptibility
Vaccines & vaccine delivery post-exposure
Rapid diagnosis
Antibiotics
Biological response modifier
Tissue growth & transplant</td>
<td>♦♦♦♦
Human genome & disease susceptibility
Vaccines & vaccine delivery post-exposure
Rapid diagnosis
Antibiotics
Biological response modifier
Pathogenicity islands
Block viral/bacterial disease</td>
<td>♦♦♦♦
Human genome & disease susceptibility
Vaccines & vaccine delivery post-exposure
Rapid diagnosis; tissue growth & transplant
Block viral/bacterial disease
Telemedicine</td>
<td>Japan
♦♦♦♦
Human genome & disease susceptibility
Vaccines & vaccine delivery post-exposure
Rapid diagnosis
Antibiotics
Tissue growth & transplant
Pathogenicity islands
Antivirals

China
♦♦♦
Antibiotics</td>
<td>♦♦♦♦
Vaccines & vaccine delivery post-exposure
Rapid diagnosis</td>
<td>♦♦♦
Vaccines</td>
<td>Switzerland
♦♦♦♦
Vaccines & vaccine delivery post-exposure
Rapid diagnosis
Antivirals

Sweden
♦♦♦♦
Antibiotics

Israel, Italy, Netherlands
♦♦♦♦</td>
</tr>
<tr><td colspan="7">MEDICAL CHEMICAL & BIOLOGICAL DEFENSE</td></tr>
<tr>
<td colspan="3">♦♦♦♦
Vaccines & vaccine delivery post-exposure; acute trauma shock; lightweight face masks for BW protection</td>
<td>Japan
♦♦♦♦
Vaccines & vaccine delivery
Post-exposure
Acute trauma shock

China
♦♦♦♦
Acute trauma shock

ROK
♦♦♦♦</td>
<td>♦♦♦♦
Vaccines & vaccine delivery post-exposure
Acute trauma shock
Lightweight face masks for BW protection</td>
<td></td>
<td>Switzerland, Netherlands, Israel
♦♦♦♦
Vaccines & vaccine delivery post-exposure
Acute trauma shock
Lightweight face masks for BW protection</td>
</tr>
<tr><td colspan="7">MILITARY OPERATIONAL MEDICINE</td></tr>
<tr>
<td colspan="3">♦♦♦♦
Biological response modifier; biomarkers for toxicant exposure; nutrient additives</td>
<td>Japan
♦♦♦♦
Biological response modifier
Biomarkers for toxicant exposure
Nutrient additives</td>
<td>♦♦
Biomarkers for toxicant exposure
Nnutrient additives
Personnel containment following CB attack</td>
<td></td>
<td>Switzerland, Sweden, Israel
♦♦♦♦
Biological response modifier
Nutrient additives</td>
</tr>
<tr><td colspan="7">COMBAT CASUALTY CARE</td></tr>
<tr>
<td colspan="3">♦♦♦♦
Telemedicine; wound healing & nervous system repair; blood replacement</td>
<td>Japan
♦♦♦♦
Telemedicine
Wound healing & nervous system repair
Blood replacement

Korea
♦♦♦
Blood replacement

China
♦♦♦</td>
<td>♦♦
Telemedicine
Wound healing & nervous system repair</td>
<td>♦♦
Artificial blood substitutes</td>
<td>Switzerland, Israel, Netherlands, Sweden
♦♦♦♦
Telemedicine
Wound healing & nervous system repair
Blood replacement</td>
</tr>
</table>

Note: See page E–6 for legend.

affected personnel for long periods after exposure to such agents. The U.K., Japan, France, Germany, Sweden, and the Netherlands are leaders in this area.

c *Military Operational Medicine*

Basic research within the Army operational medicine area provides a basic understanding of the pathophysiology of environmental and occupational threats affecting soldier health and performance. In addition to the risks to health and performance from operations in extreme and climatic environments and from the rigors imposed by military operations in and of themselves (e.g., sleep deprivation, jet lag, stress), operation of Army systems may present additional health hazards (e.g., EM radiation, noise, vibration, blast, toxic chemical byproducts).

Biomarkers for toxicant exposure in humans and animals have been identified as materials that are body catalysts and enzymes, which serve to detoxify chemicals. The absence of some of these normally occurring enzymes in specific persons has been shown to increase susceptibility to disease. It is now possible to screen blood and urine samples and determine the concentration of these biomarkers in selected persons. It is likely that biomarker profiles will have utility in selection of persons resistant to toxicants (for special operations) and for reviewing fitness for duty. The human genome project is likely to increase the number of biomolecules that can serve as biomarkers for exposure. The U.S., Canada, the EC, and Japan have expertise in this area.

d *Combat Casualty Care*

The critical areas of care for combat casualties in the next decade include treatment for fluid loss and accompanying shock; management of impact injury on the nervous system, including the spinal cord; increased susceptibility to infection at points of projectile entry because of stress-related events; and prevention of biological agent dissemination by friendly forces exposed to agents. Biocompatible materials that bind oxygen and have utility as blood-expanding agents are in development in the United States, the EC, and Japan. Cellular growth factors, acting on neural tissues, have been found to stimulate the repair of transected spinal cord and other central nervous system regions. Macromolecular growth factors, acting on tissues other than the nervous system, have been shown to enhance the rate of wound healing and to increase resistance to disease. This research is actively explored in the U.S., Canada, Germany, the U.K., France, Japan, Israel, Italy, and Sweden.

e *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in biomedical research:

- Canada—Defence and Civil Institute of Environmental Medicine [http://www.dciem.dnd.ca/DCIEM/welcome_e.html]
- Belgium—Center for the Evaluation of Vaccination, University of Antwerp [http://esoc–www.uia.ac.be/esoc/CEV/]
- Czech Republic—Department of Military Epidemiology, Purkynì Military Medical Academy [http://www.pmfhk.cz/English/index.htm]
- Switzerland—Neuroscience Center, Swiss Federal Institute of Technology [http://www.neuroscience.unizh.ch/]

11 Biological Sciences

Basic research in the biosciences increases the understanding of and ability to (1) manipulate those aspects of the biological world that affect soldier sustainment and survival, and (2) identify and characterize biological materials and processes for future exploitation in materiel systems. Specifically, biological sciences research contributes directly to a knowledge of food production in deployed areas; production of potable water; protection of military personnel from infectious agents in a deployed region; production of sensors for CB agents; reduction of signatures to increase stealth; and production of materials useful in communications, sensing, and self-assembly. Table E–22 summarizes international research capabilities in biological sciences.

TABLE E–22. BASIC RESEARCH—BIOLOGICAL SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
BIOMOLECULAR & CELLULAR MATERIALS & PROCESSES						
♦♦♦♦ Combinatorial chemistry, human genome, pathogenicity islands Characterization of receptors for biological agents, toxins, and neurotransmitters Functional MRI, PET, and systems			*Japan* ♦♦♦♦ Combinatorial chemistry Human genome, pathogenicity islands Characterization of receptors for biological agents, toxins, and neurotransmitters Functional MRI, PET, and systems ♦♦♦♦ Biomimetic optical information processing Biomimetics for lightweight protective clothing *China* ♦♦♦♦+ Combinatorial chemistry Characterization of receptors for biological agents, toxins, and neurotransmitters *India* ♦♦	♦♦– Combinatorial chemistry Human genome, pathogenicity islands Characterization of receptors for biological agents, toxins, and neurotransmitters Functional MRI, PET, and systems ♦♦♦ Biomimetic optical information processing Biomimetics for lightweight protective clothing	♦♦♦ Targeted delivery	*Netherlands, Israel, Switzerland, Sweden, Australia* ♦♦♦♦ *Italy* ♦♦♦–
MICROBIOLOGY & BIODEGRADATION						
♦♦♦♦ Bioremediation Signature reduction			*Japan* ♦♦ Bioremediation *China* ♦♦♦+ Biomimetic optical information processing	♦♦ Bioremediation Signature reduction		*Netherlands, Switzerland, Finland, Israel, Sweden* ♦♦♦♦

TABLE E–22. BASIC RESEARCH—BIOLOGICAL SCIENCES (CONT'D)

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
PHYSIOLOGY, SURVIVABILITY, & PERFORMANCE						
♦♦♦♦ Rations to enhance/sustain performance Biological response molecules Nutritional additives from microbiological or sea plant sources Encapsulation			*Japan* ♦♦♦♦ Rations to enhance/sustain performance Biological response molecules Nutritional additives from microbiological or sea plant sources Encapsulation *China* ♦♦♦♦ Rations to enhance/sustain performance Biological response molecules Nutritional additives from microbiological or sea plant sources Encapsulation	♦♦♦♦ Rations to enhance/sustain performance Biological response molecules Nutritional additives from microbiological or sea plant sources		*Netherlands, Italy, Sweden, Israel* ♦♦♦♦ Rations to enhance/sustain performance Biological response molecules Nutritional additives from microbiological or sea plant sources

Note: See page E–6 for legend.

a *Biomolecular and Cellular Materials and Processes*

Research in this area seeks to define structure function relationships and biochemical interactions for enzymes, receptors, and other macromolecules exhibiting mechanisms and properties relevant to Army interests. These include biocatalysis, ribosomal and nonribosomal biosynthesis, and metabolic engineering.

The Human Genome Project utilizes biochemistry (combinatorial chemistry), biophysics, and molecular biology to explore questions of intrinsic disease susceptibility in humans, animals, and crops. These technologies also reveal the nature of molecules that allow bacteria to infect humans, allow viruses to infect cells, and allow cells to communicate with each other (i.e., receptors). The insights gained from the Human Genome Project have resulted in the identification of gene sequences (pathogenicity islands) in biological agents that increase pathogenicity in humans and target animals. Since the effect of toxins on cells is a result of their action on specific cell receptors, these technologies reveal how we can neutralize toxins. Russia had developed expertise in the use of biological toxins to deliver molecules to specific cells. The Russian capability has decreased in many of these areas during the past 5 years, but still remains strong in targeted delivery (associated with Ministry of Defense laboratories). The U.K., Canada, Japan, Taiwan, Russia, Sweden, China, Korea, Brazil, and Israel have capabilities in these areas. A number of nations have strong programs in the characterization of biomolecules, for example, surface characterization work in China and nuclear magnetic resonance studies in Japan, the Netherlands, and the U.K.

The use of biomaterials as structural elements or as models to construct nonbiological materials that function as biomimetics has grown, as has the demand for system miniaturization. Polyhydroxybutyrate and silks are two examples of biomaterials with good tensile properties. The

U.K., France, Germany, Israel, the Netherlands, and Australia are developing advanced biomaterials for energy transduction applications. New materials emerging from nanotube technology, ceramics based on marine shell structures, and isolated bacterial rhodopsin have applications in signature reduction and information storage. Russia, in collaboration with the former DDR, utilized bacterial rhodopsin to construct a read/write device called Biochrome. The reduction in financial resources in the FSU has caused a decline in this capability. A Biochrome material is currently available from Germany. The U.K., Japan, France, the Netherlands, and Israel also have strong capabilities in this area.

Biotechnology applications can contribute to Army efforts. Large-scale production of biomaterials and products is necessary to capitalize on emerging biotechnology developments. The techniques for providing these large quantities of biomaterials (bioprocess engineering), of significant interest to the U.S. Army, include production of the material (including cell culture and fermentation), downstream product processing, and packaging.

Compared to other rapidly advancing technologies, biotechnology at the research level is relatively open. The most concerted challenges may be expected from Japan, Germany, France, the U.K., the Netherlands, Switzerland, Italy, Sweden, Russia, and certain of the other FSU and Eastern European states. Canada, Brazil, Singapore, Israel, and China are other examples of countries with strong capabilities in the basics of biotechnology upon which to build, as well as strong (in some cases world leading) capabilities in niche technologies.

Japan's well-coordinated government and industry cooperative effort provides guidance, avoiding duplicate efforts while increasing support and sharing throughout different companies. Government sponsors in biotechnology include the Council for Science and Technology; the Science and Technology Agency; MITI; the Ministry of Health and Welfare; the Ministry of Education, Science, and Culture; and the Ministry of Agriculture, Forestry, and Fisheries. Large companies (e.g., Kirin Brewery, Suntory Limited, Mitsubishi Kasei Corporation, Sumitomo Chemical Company, Takeda Chemical Industries, Tanabe Seiyaku Company, Ltd., Toray Industries, Yamanouchi Pharmaceutical Company) are important participants in Japanese biotechnology activities. These companies—traditionally strong in chemicals, pharmaceuticals, food and beverage, and textiles—now see the possibilities for additional diversification to high-value-added health care products. A Japanese consortium of Fuji and Seiko is examining the human genome. In Japan there is a close, strong relationship between industry and the university community. The relationship includes company financial support of biotechnology activities and industry personnel performing onsite research at universities.

Strong government influence is also evident in Japan's research centers. Some of the better known are the Fermentation Research Institute, the National Institute of Basic Biology, Institute of Physical and Chemical Research (RIKEN), and the New Energy and Industrial Development Organization. These centers encourage and support basic and applied research in virtually all of the key areas of biotechnology identified in this Advanced Technology Assessment Report. They also help the larger governmental agencies identify key directions that Japanese biotechnology R&D efforts should take.

Several institutes are essentially dedicated to biotechnology: Osaka Bioscience Institute, National Institute of Agrobiological Resources, National Institute of Sericultural and Entomological Science, Fermentation Research Institute, and Nippon Institute for Biological Science. Molecular biology, cell biology, and enzymes are the main research activities at the Osaka Bioscience Institute. Major areas of research at the National Institute of Agrobiological Resources

include molecular and cellular biology, genetic engineering (such as recombinant DNA), and bioprocessing (cell fusion). The National Institute of Sericultural and Entomological Science is studying silk culture. This has mainly been restricted to silkworm silk for commercial purposes and is only generically related to spider silk. However, they are currently collecting information on other insects. The Fermentation Research Institute conducts a broad range of activities in bioprocessing. These include recombinant DNA, bioreactors using immobilized enzymes, and cell growth. The Nippon Institute for Biological Science' research projects cover a wide area of genetic engineering.

Germany, because of its strong industrial base and major presence in pharmaceutical and brewing areas, is generally considered to have the strongest capability for biotechnology within the EC. They are well positioned to challenge the United States and Japan, and to become a world leader in biotechnology. The Bundesministerim f□r Forschung und Technologie Federal Ministry for Research and Technology, the DECHEMA Chemical Plant Association, and the GBF Institute for Biotechnology Research are important biotechnology development centers. Germany is one of the participating nations in NATO PG 31, which deals with development of enzyme-based systems for decontamination of CW agents. This effort is coordinated through the Defense Science Agency for NBC Protection.

The GBF Institute has achieved worldwide fame for its work in fermentation processes and technology. Areas of research interest at GBF are separation, sequencing, and purification of products; enzyme and microbial transformation; genetic engineering; bioreactor design and process control; protein engineering and modeling; and biosensor technology. In addition, the Biotechnology Information Knot for Europe, a database/information base of biotechnology, is maintained at GBF. The Institute for Biotechnology, another German organization devoted to biotechnology, is instrumental in microbial degradation of polymers and use of enzymes (cellulose and hemicellulose, etc.).

The Max Planck Institute and other government-funded organizations are primarily research-related and provide a solid basis for further advances in German biotechnology. Germany's university structure—University of Technical Chemistry at the University of Hannover, the Institute of Biochemistry and Molecular Biology at the Technical University of Berlin, the Institute for Biochemistry at Free University of Berlin, as well as others—provides strong capabilities in most biotechnology-related research areas. The industrial sector has numerous large, multinational corporations founded in Germany, such as Bayer and Hoechst. Many smaller German firms are making significant advances in biotechnology, especially in areas like enzyme production, biological pesticides/insecticides, fertilizers, and pharmaceuticals. The German chemical firm Degussa has shown considerable interest in amino acids. However, no European firm has the capability exhibited by the Japanese in this area.

The U.K. is generally cited as having a strong biotechnology capability within the EC, only slightly trailing Germany. The U.K.'s initial biotechnology emphasis was focused on genetic engineering; however, fermentation, bioreactors, and chemical engineering areas are now receiving considerable interest and support from government, academia, and industry. The U.K. is one of the participating nations in ITF24, which deals with emerging technologies for the detection and identification of biological agents. This effort falls under a memorandum of agreement on CB defensive material. Government agencies providing support and resources to promote biotechnology advances in the U.K. are MRC, SERC, and the Biotechnology Division of the Department of Trade and Industry. These agencies provide funding, develop and implement

policy, encourage research, and provide guidance and oversight to academia, industry, associations, and any collaboration among these participants. Many universities and industries are closely associated through cooperative ventures. This synergy promotes university research efforts and graduate education while providing industry with promising projects.

Biotechnology projects in the U.K. will continue to improve and grow because of the strong foundation provided by academia/industry. The U.K. university system is one of the best in the world in biotechnology. Numerous colleges and universities have ongoing research programs in many different biotechnology areas. Some major areas of emphasis are fermentation mixing, scale-up, and pilot plant development of bioreactors; immunoaffinity materials for downstream processing; monoclonal antibody production and hybridoma cell growth; genetic engineering; biosensors; thermal stable enzymes; chemically sensitive fiber-optic sensors; biodegradation techniques; and bioelectronics.

FRENCH BIOTECHNOLOGY PARTICIPANTS

Genetic engineering

- CNRS [http://www.cnrs.fr/]
- Institut National de la Recherche Agronomique
- Institut Pasteur
- Institut National de la Sante et de la Recherche Medicale

Photosynthesis and radioisotopic metabolism

- Commissariat a l'Energie Atomique

Hybridoma technology, virology, and immunology

- Institut Pasteur [http://www.pasteur.fr/]

Biological reactors; catalysis, production, and purification of enzymes; immobilization of enzymes; and fermentation techniques:

- Laboratory of Chemical Genetics (division of CNRS)
- National Polytechnic Institute of Lorraine
- Laboratory of Biopharmacology—CNRS, Tours
- National Institute for Applied Chemical Research (also production of synthetic peptide intermediate compounds (amino acids, oligopeptides, phosphorylated derivatives)).

Bioinformatics (algorithms, software, and hardware tools) to monitor and control bioreactors, biotechnological processes optimizing yield and quality, and related M&S techniques:

- National Polytechnic Institute of Grenoble

Industrial biotechnology:

Rhone–Poulenc	Roche
Roussel–Uclaf	Ciba–Geigy
Sanofi	Shering–Plough
Merck	l'Oreal

France participates in a number of joint projects with the EC. However, they have strong national aspirations as well. In the 1980s, the French government initiated an aggressive biotechnology development program designed to make them the European leader by 2000. Their aim is to capture 10 percent of the world's market in biologically derived substances. The French Committee for Strategic Industrial Development committed millions of dollars with matching industry funds to numerous biotechnology projects. France is also a member of NATO PG 31 for developing enzyme-based decontaminants. The primary research facility involved is the CEB, Vert–le–Petit.

Because France perceives itself as lagging behind its major European counterparts—Germany and the U.K.—it decided to place particular emphasis on long-term means (e.g., education, training) to achieve its goal. The leading research institutes and university centers identify candidate biotechnology areas for establishing and developing products. One of the major handicaps of the French biotechnology program is the lack of cooperation between industry (applied uses) and the university (academic research). To facilitate better exchange of ideas and promote commercial application of research, a number of joint technology centers were established (Compiegne, Toulouse, Institut Pasteur, and Paris–Grignon University).

The success of recent collaboration between industry and academia has promoted projects sponsored by industry and government. One major public–private sector collaborative initiative—the Intergene Program—is leading France's research efforts in immunoenzymology, bacterial

immunology, parasitic and viral immunology, monoclonal antibodies, and enzyme purification. The government participants of this effort are CNRS, the Institut National de la Sante et de la Recherche Medicale, and the Ministry of Research and Technology; Transgene, Immunotech, and Bio–Merieux are the private sector players.

Before the dissolution of the FSU, the Soviet Union led a strong biotechnology effort, linked cooperatively with its Eastern European allies by the Council for Mutual Economic Assistance. Different countries emphasized different points of biophysical research. Primary emphases of biotechnology efforts within the FSU, as in other nations, include drugs, vaccines, and agricultural applications. Russian work includes virtually all of the basic elements of generic biotechnology. The theoretical and analytical work done is strong and of high quality. Specific subtechnologies include recombinant DNA and protein engineering, self assembly, enzyme immobilization, and Langmuir–Blodgett films. Their discoveries and achievements—their understanding of the molecular mechanisms whereby neurons process information, their development of Biochrome bacteriorhodopsin-based film, and the use of dynamic chemical reactions for image processing—indicate a substantial capability. The development of Biochrome film (a highly stable and fast-response (picoseconds) membrane capable of bistable switching) is particularly significant. First, it demonstrates a strong level of understanding and capability in basic biotechnology that could lead to protein engineering techniques to produce materials with optimized functional capabilities. Equally important, successful demonstration of bistable materials opens possibilities for application of biomaterials to important information storage, processing, and computational applications.

b *Microbiology and Biodegradation*

Microbiology is an essential science in the production of fermented and processed foods (bread, yogurt, beer, wine), of pharmaceuticals and human hormones (the latter using genetic engineering), and in evaluating human performance (neural function, vital signs). The U.K., Japan, Germany, France, and Russia have a long tradition of expertise in this areas. Hungary has an established capability in the production of fermenters. China has a developing capability in nutrient additives and biological response modifiers.

Remediation of soils and water using biological organisms to metabolize contaminants has been an area of extensive research in the past decade. The U.K., France, Germany, the Netherlands, Sweden, Finland, Japan, Russia, and Israel have expertise in this area, with the U.K. and Israel particularly active in water purification.

c *Physiology, Survivability, and Performance*

This area includes research on how organisms respond and adapt to environmental signals and the strategies they employ to survive adverse environmental conditions. Other research of interest includes work in nutrient additives, protein stabilizers, sugar modification, and synthesis of biopolymers for use as elastomers in food containers. Encapsulation and irradiation technologies have been used to increase shelf life, and encapsulation also increases palatability. Most EC nations and Japan have advanced food technology programs. Strong capability in the use of biopolymers as packaging primarily resides in the EC.

d *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in biological sciences:

- France—Center for Molecular Biophysics, CNRS—University of Orléans [http://www.cnrs.fr]
- Netherlands—Graduate School of Food Technology, Agrobiotechnology, Nutrition, and Health Sciences, Wageningen Agricultural University
- United Kingdom—Center for Biomimetics, University of Reading [http://www.reading.ac.uk/AcaDepts/cb/home.htm]

12 Behavioral, Cognitive, and Neural Sciences

Basic research in the Army Behavioral, Cognitive, and Neural Sciences (BCNS) program seeks the scientific understanding of factors that enhance or diminish performance of soldiers in units. Table E–23 summarizes the research capabilities of the international research community in BCNS.

TABLE E–23. BASIC RESEARCH—BEHAVIORAL, COGNITIVE, AND NEURAL SCIENCES

United Kingdom	France	Germany	Japan/Asia	Russia	Canada	Other Countries
			TRAINING			
♦♦♦♦–	♦♦♦	♦♦♦♦	*Japan* ♦♦♦+	♦♦♦–	♦♦♦♦	*Israel* ♦♦♦
			PERSONNEL			
♦♦♦	♦♦	♦♦	*Japan* ♦♦ *Philippines, Singapore* ♦♦+	♦	♦♦♦	*Israel, Australia* ♦♦♦ *Eastern Europe* ♦♦
			LEADERSHIP			
♦♦♦♦	♦♦♦	♦♦♦	*Japan* ♦♦♦♦	♦	♦♦♦♦	*Israel* ♦♦♦ *Australia* ♦♦
			VISUAL & AUDITORY PROCESSES			
♦♦♦♦	♦♦♦	♦♦♦♦	*Japan* ♦♦♦	♦♦♦	♦♦♦♦	*Netherlands, Israel* ♦♦♦ *Australia* ♦♦
			STRESS & COGNITIVE PROCESSES			
♦♦♦♦	♦♦	♦♦	*Japan* ♦♦	♦♦		*Israel* ♦♦♦♦
			SOLDIER INTERFACE			
♦♦♦	♦♦♦	♦♦♦♦	*Japan* ♦♦♦	♦♦♦		*Israel, Australia* ♦♦♦

Note: See page E–6 for legend.

a *Training*

Training research concerns how individual soldiers acquire, process, store, and use information. Traditional issues include speed of learning, rate of forgetting, and the transfer of skills from one set of conditions (e.g., a simulator) to another set (e.g., performance on the actual equipment). Training research is also expanding to development of mental models that underlie complex task performance. Results from this research are used to develop effective technologies for training soldiers.

Wide-ranging programs of basic research on skill acquisition, retention, and transfer are supported by many major universities and research institutions in Northern Europe (particularly in the U.K. and Germany) and in Canada. These countries routinely collaborate with U.S. scientists on issues relating to learning, memory, and cognition. Israel and Japan also maintain significant research infrastructures for most topics in this area, though not as broadly based as the former mentioned countries. The FSU had significant basic research programs in learning and memory, but their capabilities are in decline. Asia and Pacific Rim countries have relatively small programs, but they are perceived as growing in capabilities.

b *Personnel*

The goal of personnel research is to provide a scientific and technical basis for methods related to recruiting, selecting, assigning, and retaining the best personnel possible. For selection and assignment methods, the fundamental issues relate to the theory and practice of assessing job aptitudes and abilities. Recruitment and retention methods are founded on theories relating to attitude formation and stability. Other relevant issues in personnel research include personal opinions and behaviors toward diversity and other societal issues. Results from research in this area often have direct implications for military personnel acquisition and retention policies.

The United States is the clear leader in personnel research, but English-speaking countries (in particular, the U.K., Canada, and Australia) have significant capabilities. Israel also has a few academic programs in personnel research. Other countries lesser capabilities are the Philippines and Singapore. Also, some academic programs in personnel research are implemented in Israel. It is interesting to note that some Central European countries (Hungary and Slovakia) and Turkey have small but growing capabilities for conducting personnel research.

c *Leadership*

Leadership research is concerned with identifying characteristics of effective military leaders with direct implications for designing programs for (1) developing leadership competencies in junior commissioned and noncommissioned officers, and (2) broadening and strengthening these competencies in senior military leaders. Such competencies include the ability to manage others, coordinate activities, inspire groups, train individuals and teams, and make decisions. This research also assumes that leadership is conditioned and constrained by important social context factors, such as the communications infrastructure. The goal of leadership research is to develop and promote leadership skills that enhance the effectiveness of Army units.

Leadership is a traditional area of study within social psychology and, as such, is a staple teaching and research topic in most academic psychology and sociology programs in developed countries. However, research in leadership has not been as active as in previous decades. This is partly because some of the traditional issues in leadership (e.g., decisionmaking) have been subsumed by other topics (e.g., training). Furthermore, in leadership, more than in any other

research area, cultural differences may limit collaborative efforts to countries that share our basic concepts. Specifically, the highly individualistic and aggressive leadership style admired in the United States and other English-speaking countries may not be as relevant to other countries that do not share the same cultural background. An exception to this generalization, however, is the activity in leadership research in Japan. For example, Jyuji Misumi's Performance–Maintenance theory of leadership has had a significant impact on research in the United States and other countries.

d *Visual and Auditory Processes*

The goal of research in this area is to understand the visual system, the primary stimulus input channel for human information processing. Specific issues of interest to the Army include divided attention (particularly as it influences the use of HMDs), night operations, and tele-operations. Research on visual processes intersects with training research on the issue of instruction on C^2 tasks in the context of VR and DIS technologies.

Visual processing and perception are central topics in experimental psychology, as well as in clinical research in ophthalmology and optometry. Many universities in most developed countries conduct some form of research in these areas. A high level of active research is maintained in Northern Europe and is particularly strong in Germany, reflecting its long history of research in psychophysics. Japan has an interest in the psychophysics of vision, particularly as it applies to the engineering of visual displays. A substantial vision research infrastructure is also maintained in the U.K. and in the Netherlands. Active research is also ongoing in Russia and the rest of the FSU. Research on the physiology of vision is ongoing in Australia.

The goal of auditory process research is to develop a better understanding of audition from both the biological and the information processing points of view. The challenge is to protect a soldier's hearing on the noisy battlefield while enhancing the soldier's capability to detect important sources of auditory information. An important topic is how auditory signal processing interacts with other sensory modalities, the most important being vision.

Auditory processes are studied by a variety of disciplines, including the clinical field of otology, physics, psychology, and (recently) computer science. Germany continues its long history of research in psychophysical research on auditory processing. Research is also strong in the rest of Northern Europe, Japan, and Canada. Research on the physiology of audition is underway in Australia.

e *Stress and Cognitive Processes*

An important and unique consideration for human performance research in the Army is that soldiers must able to perform combat tasks under stressful conditions brought on by high rates of physical or mental effort, physical exhaustion, or emotional responses to threat. Goals for research in this area are to identify and describe human responses to such stressful conditions and to develop interventions for ameliorating its negative effects.

Israel has a comparatively long history of authoritative research on combat stress, as conducted by the Israeli Institute for Military Studies and at other universities. Considerable work is performed on combat stress within the military research establishments of other countries as well, such as research on post-traumatic stress syndrome being performed by the U.K.'s Ministry of Defence. Some research on work-related stress is being performed in Northern European coun-

tries. For example, the National Institute for Working Life in Sweden is primarily focused on civilian jobs, but selected areas of expertise (e.g., effects of environmental stresses) are also applicable to military jobs.

f *Soldier Interface*

Research in soldier interfaces concerns the intersection of human and machine, particularly in the developing context of the digital battlefield. The advanced sensors and improved communications afforded by digitization of the Army dramatically increase the amount of information impinging on soldiers. The goal of research in this area is to design interfaces and procedures that allow soldiers to benefit from the advantages of these new technologies and to avoid the potentially negative effects of information overload.

High-technology firms in many developed countries are developing computer technologies that will provide the infrastructure for the digital battlefield. In particular, industries in the U.K. and Israel are active in developing portable, soldier-friendly technologies to aid tactical decision-making. With respect to the more academic issues related to the soldier–machine interface, scientists in Germany are conducting multidisciplinary research incorporating cognitive science, ergonomics, systems engineering, and software/information engineering. In addition, the U.K. is particularly active in task analyses used to support development of appropriate HCIs.

g *Example Research Facilities*

The following facilities have demonstrated expertise for providing cooperative opportunities in behavioral, cognitive, and neural sciences:

- United Kingdom—MRC Interdisciplinary Research Centre for Cognitive Neuroscience [http://www.cogneuro.ox.ac.uk]
- Israel—Institute of Information Processing and Decision Making, Program in Cognitive Psychology and Human Factors, University of Haifa [http://psy.haifa.ac.il/~iipdm/]
- Canada—Auditory Research Laboratory, McGill University [http://www.psych.mcgill.ca/labs/auditory/laboratory.html]
- Federation of European Psychophysiological Societies [http://www.psychol.uni–giessen.de/abteil/klinisch/fmri.htm]
- European Computer Vision Network (ECV Net).

D POINTS OF CONTACT

Ms. Annette Chomsky
CECOM, RDEC
AMSEL–RD IW–OPP (Chomsky)
Ft. Monmouth, NJ 07703
e-mail: annette.chomsky@mail1.monmouth.army.mil

Mr. Stephen Cohn
Army Research Laboratory
AMSTL–TT–IP
2800 Powder Mill Road
Adelphi, MD 20783–1197
e-mail scohn@arl.army.mil

Mr. Dennis Earley
AMCOM Aviation RDEC
Bldg. 5678, AMSAM–AR–N
Redstone Arsenal, AL 35898
e-mail: Dennis.Earley@redstone.army.mil

Dr. George R. Famini/Ms. Juanita M. Keesee
SBCCOM
AMSSB–RAS–I
Aberdeen Proving Ground, MD 21010–5423
e-mail: George.Famini@sbccom.apgea.army.mil
e-mail: Juanita.Keesee@sbccom.apgea.army.mil

Dr. Stephen L. Goldberg
Chief, Army Research Institute's Simulation Systems Research Unit
12350 Research Parkway
Orlando, FL 32826–3276
e-mail: goldbers@stricom.army.mil

Ms. Jan Lanza
U.S. Army Natick Soldier Center SBCCOM
Attn: AMSSB–RSS–I(N)
Natick, MA 01760–5015
e-mail: jan.lanza@natick.army.mil

Mr. John Daniele
U.S. Army Simulation, Training, and Instrumentation Command
12350 Research Parkway
Orlando, FL 32826–3276
e-mail: john_daniele@stricom.army.mil

Mr. Ed Lowe
U.S. Army Tank–automotive and Armaments Command
AMSTA–TR–D, MS 273
Warren, MI 48397–5000
e-mail: lowee@tacom.army.mil

Mr. Ken Fleming
U.S. Army Corps of Engineers
CECS–OS
20 Massachusetts Avenue, NW
Washington, DC 20314–1000
e-mail: kenneth.m.fleming@usace.army.mil

Ms. Rosemary Dellera
U.S. Army CECOM
ATTN: AMSEL–RD–AS–TI
Ft. Monmouth, NJ 07703
e-mail: rosemary.dellera@mail1.monmouth.army.mil

Mr. Dan Shumate
AMSAM RE–TI
U.S. Army Aviation and Missile Command
Redstone Arsenal, AL 35803
e-mail: dan.shumate@rdec.redstone.army.mil

Dr. Rodney Smith
Army Materiel Command
AMXIP–O
5001 Eisenhower Avenue
Alexandria, VA 22333–0001
e-mail: rsmith@hqamc.army.mil

Mr. Gene B. Wiehagen
U.S. Army Simulation, Training, and Instrumentation Command
12350 Research Parkway
Orlando, FL 32826–3276
e-mail: gene_wiehagen@stricom.army.mil

ANNEX

F INFRASTRUCTURE

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ANNEX

F INFRASTRUCTURE

The Army transformation strategy for the development of the Future Combat Systems (FCS) and Objective Force technologies will be achieved through the Army's strong, viable, in–house research capability. Laboratories, together with research, development, and engineering centers (RDECs), are the key organizations responsible for technical leadership, scientific advancement, and support for the acquisition process. The organizational structure of the current Army science and technology (S&T) program is illustrated in Figure F–1. The geographical locations of the research sites are shown in Figure F–2.

The Army maintains world-class research, development, and testing facilities. These facilities are equipped with modern equipment and staffed with personnel capable of using the assets provided. This infrastructure is designed to meet the developmental needs of the land combat force and provide the effective transfer of developing technologies to the civilian as well as military sectors.

The Army continues a multifaceted approach to support and maintain its infrastructure. Appropriated funds are used to construct, purchase, and maintain unique equipment and facilities. As appropriate, equipment items or facilities that are developed during a specific program are

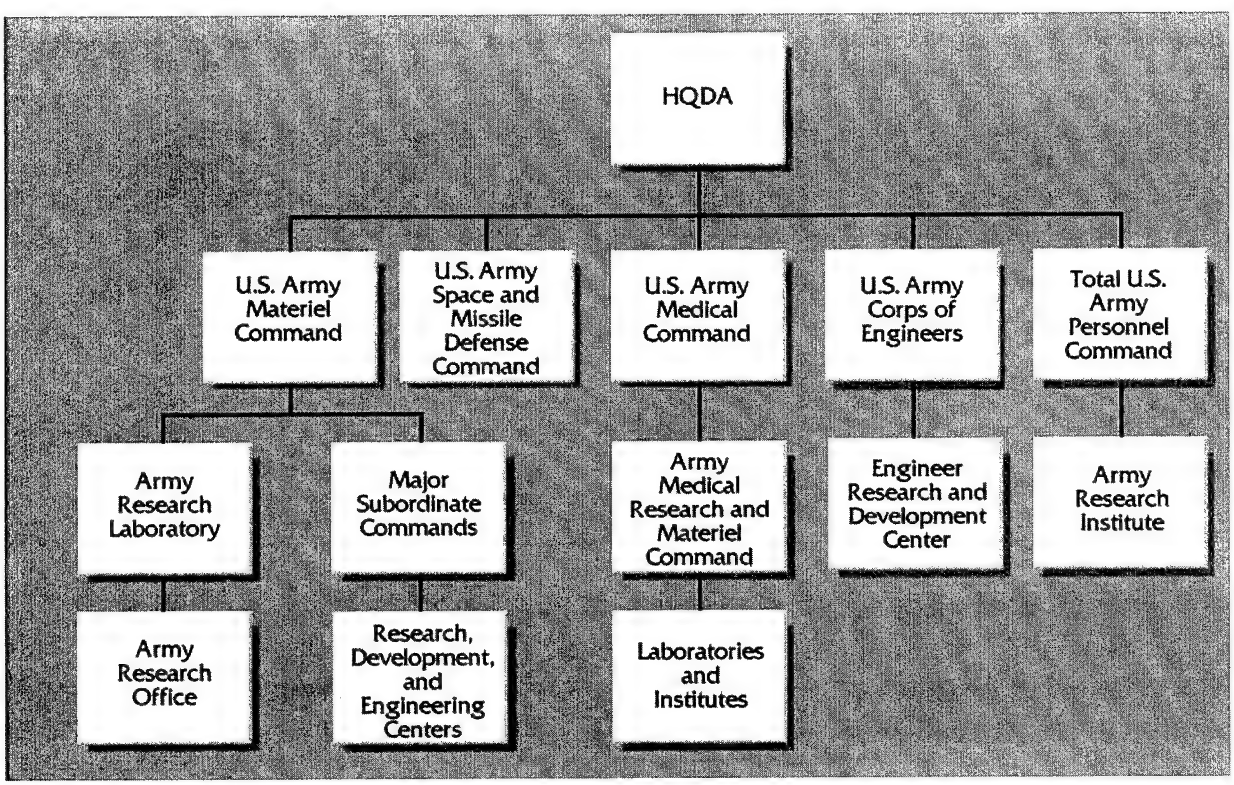


FIGURE F–1. ARMY SCIENCE AND TECHNOLOGY ORGANIZATION

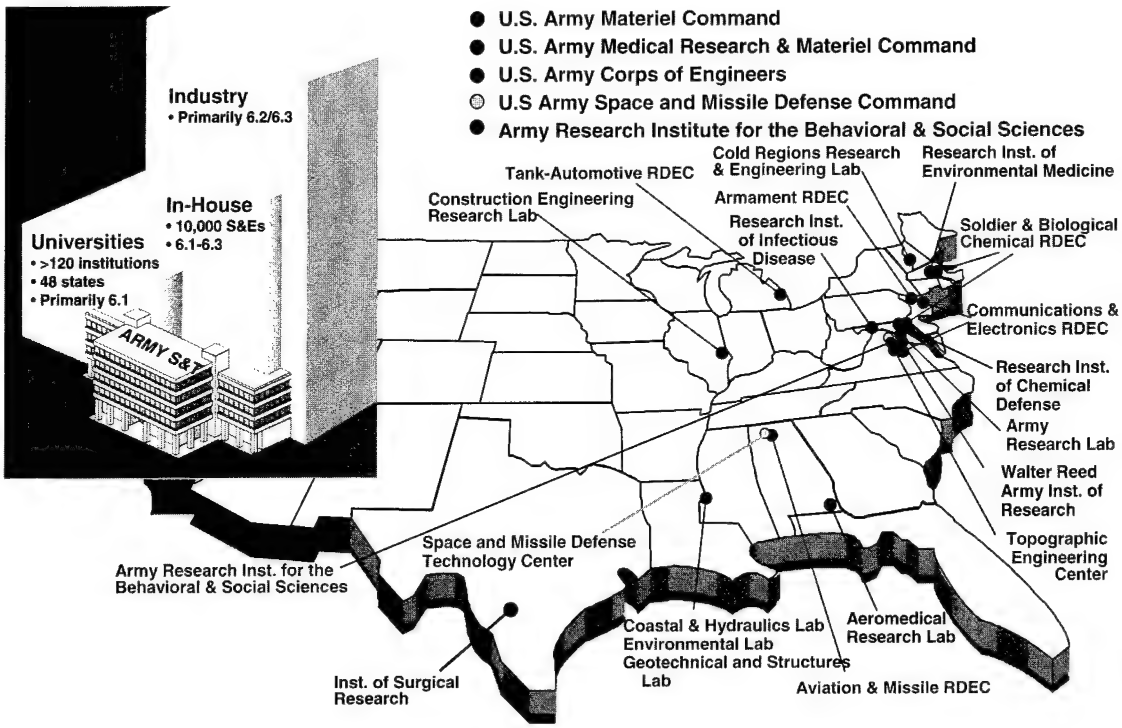


FIGURE F–2. ARMY RESEARCH AND DEVELOPMENT RESOURCES INVOLVED IN SCIENCE AND TECHNOLOGY

retained and modified to meet additional R&D needs. The Army continues to expand modeling and simulation (M&S) capacities to reduce costs of materiel development, improve safety, and shorten developmental schedules. Finally, the Army leverages the facility investments of external organizations by sharing the facilities that contribute to Army objectives.

The Army's supporting R&D infrastructure includes (1) the Federated Laboratory (FedLab) initiative, which was instituted in FY95 by the Army Research Laboratory (ARL) and is discussed in Chapter V, Volume I, (2) physical facilities and equipment, (3) advanced distributed simulation (ADS), (4) modeling, software, and testbeds, (5) information technology and communications, and (6) personnel.

This annex addresses these capabilities at Army installations and those available to the Army through working relationships with other organizations. Examples of successful cooperation and descriptions of how the Army has benefited are presented. Also highlighted are Army plans to enhance and improve existing capabilities through investment and leveraging.

Keeping the infrastructure up to date demands a monetary investment that is consistent with the needs of the materiel, combat, operational, and training development communities. It also involves internal investment in S&T to provide added technology to meet modernization objectives. Science and Technology Objectives (Annex A) enhance the Army's ability to support materiel development and support advances in gaming and modeling battlefield operations and doctrine.

A PHYSICAL FACILITIES AND EQUIPMENT

1 Physical Plant

a *U.S. Army Corps of Engineers*

ERDC SITES
Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH
Construction Engineering Research Laboratories (CERL), Champaign, IL
Topographic Engineering Center (TEC), Alexandria, VA
Coastal Hydraulics Laboratory (CHL), Vicksburg, MS
Geotechnical and Structures Laboratory (GSL), Vicksburg, MS
Information Technology Laboratory (ITL), Vicksburg, MS
Environmental Laboratory (EL), Vicksburg, MS

The Engineer Research and Development Center (ERDC) is the U.S. Army Corps of Engineers' distributed research and development command and is headquartered in Vicksburg, MS. ERDC provides world-renowned scientists and engineers who have access to the latest in specialized equipment to address problems facing the military and the nation. Research support includes mapping and terrain analysis; infrastructure design, construction, operations and maintenance; structural engineering; cold regions and ice engineering; coastal and hydraulic engineering; environmental quality; geotechnical engineering; and high-performance computing and information technology.

ERDC employs 2,500 civilian and military personnel and has an annual program of $430 million. The ERDC has $1.3 billion in facilities and equipment, including some of the most unique and modern research facilities in the world. The consolidation of the seven corps laboratories brings together the following specialized facilities and missions.

1) Cold Regions Research and Engineering Laboratory

CRREL facilities are specifically designed for the study of ice, snow, and frozen ground. The main laboratory contains 24 cold rooms that can be operated at temperatures as low as –50°F, and other specialized facilities such as the Frost Effects Research Facility, the Ice Engineering Research Facility, the Remote Sensing and Geographic Information Systems Center, and the Geophysical Research Facility. CRREL also maintains a Permafrost Tunnel in Fox, AK, and an Alaskan Projects Office at Fort Wainwright in Fairbanks, AK.

2) Construction Engineering Research Laboratory

CERL accommodates specialized facilities, including the Heating, Ventilation, and Air Conditioning (HVAC) Test Facility, which can be configured to replicate a variety of HVAC system types, including single– or dual–duct and variable air volume or constant volume. Also located at CERL is the Triaxial Earthquake and Shock Simulator, a unique dual–mode shock and vibration test facility. Another innovative part of CERL's facilities technology laboratory is the Paint Technology Center (PTC). The PTC supports the Corps' painting activities by offering assistance through consultation, specification testing, training, research, and inspection or management aids.

3) Topographic Engineering Center

TEC possesses an intricate communications infrastructure that provides extensive links between TEC and other Army and DoD organizations. TEC is the garrison location for Eagle Vision II, a mobile proof–of–concept system designed to provide the assured receipt of commercial imagery via direct downlink to support the Army's mission. TEC also houses the Integration and Evaluation Center (IEC), which is used to demonstrate and evaluate technologies, concepts, and architectures that support the Joint Precision Strike (JPS) Demonstration and other programs. In

its operational mission, TEC serves as the Army's primary agent for terrain analysis and DoD's primary agent for maintaining the water resources database and water detection. TEC also provides technical leadership for the orderly, cost-effective integration of digital terrain data into Army systems and activities providing the warfighter with a superior knowledge of the battlefield and supporting the nation's civil and environmental initiatives.

4) Coastal Hydraulics Laboratory

CHL offers unparalleled expertise in shoreline and beach erosion control; flooding and storm protection; design, construction, and maintenance of navigation channels, harbors, hydraulic structures, reservoirs locks, levees, and channel realignments for navigation and flood control; coastal and inland dredging; shoaling; salinity problems; groundwater modeling; military logistics-over-the-shore; hydrology; and hydroenvironmental modeling.

5) Geotechnical and Structures Laboratory

GSL conducts research in soil and rock mechanics, earthquake engineering and geophysics, vehicle mobility and trafficability, and pavements technology. GSL also researches the response of structures to weapon effects and other loadings, investigates methods for making concrete and other materials more durable and economical, studies the application of explosives technology to combat engineering, and investigates the behavior of earth and structure systems subjected to blast loading and projectile penetration.

6) Information Technology Laboratory

ITL is the preeminent engineering information technology organization in DoD. It supports the research missions of ERDC, other Corps activities, the Army, DoD, and other agencies by conceiving, planning, managing, conducting, and coordinating R&D in high-performance computing, computer-aided and interdisciplinary engineering, computer science, information technology, and instrumentation systems. Through a balanced program of R&D and demonstration, ITL advances the Army's knowledge and ability to use advanced information technology to address a wide range of engineering and scientific challenges.

7) Environmental Laboratory

The EL examines the interaction between man and the environment. Environmental expertise is applied to the ecology of estuarine, marine, and freshwater areas; natural and cultural resources management; water quality; management of aquatic nuisance species; projects relating to the environmental impact of dredging and dredged material disposal; wetlands; protection and enhancement of threatened and endangered species; and environmental cleanup and restoration (waste site characterization and treatment of organic waste, explosives, and heavy metals).

b *Simulation, Training, and Instrumentation Command*

STRICOM is colocated in Orlando, FL, with the Naval Air Warfare Training Systems Division, Joint Simulation System Joint Program Office, Air Force Agency for Modeling and Simulation, and Marine Corps Program Office. STRICOM, Navy, Air Force, Marine Corps, and many local defense contractors make central Florida a center for DoD simulation activities.

Advanced distributed simulation continues as a major focus of this command. This program develops and demonstrates M&S technologies for advancing the training readiness of combat

units, weapon system acquisition, and testing. Its focus is on the general linkage of simulations/simulators and networked distributed simulations and includes support of DoD's high level architecture (HLA) program. Key elements of this program are described in the following paragraphs.

Advanced distributed learning (ADL) leverages the full power of computer, information, and communications technologies through the use of common standards that provide learning tailored to individual needs and delivered anytime, anywhere. STRICOM's goal is to support ADL programs through the introduction of innovative training technology solutions, full life-cycle support, and effective program management. STRICOM is a member of the Joint ADL Co-Lab.

ICT RESEARCH VECTORS

Immersion: providing compelling realistic experiences

Networking and databases: efficient storing, organizing, and distribution of content

Story: interactive narrative that propel experience

Characters: replacing human participants with automated ones

Setup: authoring and initializing environments

Direction: monitoring and controlling experiences

The Institute for Creative Technologies (ICT) will partner with the entertainment industry to strategically advance the Army's knowledge, expertise, and capabilities in M&S technologies to support military acquisition, analysis, and training in the 21st century. The 1997 National Research Council's report, "Modeling and Simulation Linking Entertainment and Defense" sponsored by DMSO, identified the technology potential for leveraging DoD and entertainment research.

In August 1999, DDR&E approved the University of Southern California ICT as a university-affiliated research center (UARC). Its purpose is to capitalize on the entertainment industry's technology for human immersion into virtual reality with the intent of sharpening the Army's use of modeling and simulation. Figure F–3 illustrates a first example of this exploitation. It is a "still" of an interactive scenario in which a junior Army officer reacts to developments in a Bosnian-like scenario. The officer, leading his platoon to take up positions in a small village, is confronted with an accident in which one of his vehicles has struck a local

FIGURE F–3. ADVANCED SIMULATION TECHNOLOGY: MISSION REHEARSAL EXERCISE

national's car and seriously injured a young boy. The avatar in the graphic is the lieutenant's platoon sergeant, and he explains the situation to the officer to obtain a decision for action. Once a decision is voiced by the lieutenant, the scenario plays out confronting the lieutenant with the consequences of his decision. The intent of the emmersion scenario is to vicariously expose soldiers to difficult situations so that they might learn how to deal with them before they encounter them in a real event.

The goal of the Inter-Vehicle Embedded Simulation and Training (INVEST) program is to develop and demonstrate an in-vehicle distributed simulation capability employing reusable components, interfaces, tutoring systems, take-home packages, and scenarios. Embedded training is a goal of the FCS program.

c *Army Research Laboratory*

ARL is continuing to upgrade facilities to accommodate consolidations and incoming R&D activities that are relocating under the 1991 Base Realignment and Closure (BRAC) Commission decision. Construction at Aldephi Laboratory Center will accommodate the mandated BRAC91 relocation of functions from White Sands Missile Range (WSMR), NM, Fort Monmouth, NJ, and Fort Belvoir, VA. The total construction program added approximately 320,000 square feet to the installation at a cost of $77 million. The $60 million physical sciences building will house the sensor and electronic device personnel relocated from Fort Monmouth, the Sensors Directorate relocated from Fort Belvoir, and the Division of the Computational and Information Science Directorate (CISD).

The computer center will connect with the high-performance and simulation computers located at Aberdeen Proving Ground (APG). The physical sciences building was completed in 1998. The high-bay facility accommodates the CISD's research in atmospheric science. It provides loading, transfer, and testing capabilities of special meteorological field research equipment. Construction at APG includes a Materials Research Facility (MRF), an out-of-laboratory facility, and a target assembly and storage facility. The recently completed MRF supports a wide range of basic material research as well as research by other government and private customers.

The out-of-laboratory facility provides for electromagnetic pulse survivability and vulnerability analysis and testing capabilities for all of DoD. Vulnerabilities are found through exposure to low–level fields and verified with current injection devices. The Target Assembly and Storage Facility at APG accommodates the assembly and storage of classified targets and provides the specialized capability for working with heavy–metal armor, such as depleted uranium. The Army Research Office (ARO), a part of ARL, located in Research Triangle Park, NC, is dedicated to promoting basic research. Its proximity to Duke University, North Carolina State University, and the University of North Carolina facilitates its mission. Many facilities have been developed in partnership or under a leveraging agreement with other services, government organizations, industry, or academia.

d *U.S. Army Space and Missile Defense Command*

SMDC operates or funds several support capabilities that enhance Army S&T with data and information derived from assessments, analyses, experiments, and tests of both strategic and tactical systems. The SMDC Battle Laboratory has a high-performance computing distribution center consisting of the Advanced Research Center and the Simulation Center, both in Huntsville, AL. These centers are contractor-operated facilities that consist of government-

owned, general-purpose application development processors that provide a wide range of architectures. These resources can be configured to support a variety of experiments and developmental activities. Six hundred scientists and engineers perform computationally intensive tasks such as investigating nuclear, optical, and radar system effects; optical signature codes; and computational fluid dynamics codes.

e *Edgewood Chemical Biological Center*

ECBC maintains surety agent research facilities to support the Army's chemical and biological defense programs. ECBC laboratories, equipped with security measures, fume hoods, and exhaust filtration units, perform research and product acceptance work with toxic materials.

Analogous facilities for investigating medical countermeasures (CM) are found at the U.S. Army Medical Research Institute of Chemical Defense. Colocated with it is the Nuclear Magnetic Resonance Laboratory, the only U.S. facility certified to work with chemical surety materials—which identifies agents, degradation products, and impurities. The colocation of these facilities reduces duplication of effort and administrative costs generated by the particularly sensitive nature of the stored and handled products.

At the Communications–Electronics Command (CECOM), ECBC has a dynamic facility that can be rapidly reconfigured to replicate existing and evolving tactical command, control, communications, and intelligence and electronic warfare (EW) battlefield environments. The Digital Integrated Laboratory (DIL) testbed enables comprehensive evaluations of prototypes, evolutionary system developments, new technologies, commercial products, and systems interoperability. It interfaces with the battle labs supporting Advanced Technology Demonstrations (ATDs) and Advanced Warfighting Experiments (AWEs), field sites, contractor testbeds, and simulations staffed with technical engineering experts. DIL is a fundamental component for systems engineering and integration that focuses on battlefield intelligence, surveillance, situational awareness, combat identification, targeting, and battle damage assessment. External sites connected to DIL include:

- Battle Command Battle Laboratories (BCBLs) at Fort Gordon, GA, and Fort Leavenworth, KS.
- Army Battle Command Systems Laboratory at Fort Monmouth, NJ.
- Joint Interoperability Test and Technology Integration Center at Fort Huachuca, AZ.

The virtual prototyping infrastructure at the Army Tank–Automotive RDEC (TARDEC) is revolutionizing the military ground vehicle development process. The facility demonstrates distributed virtual prototyping activities to integrate and interface advanced concepts in mobility, survivability, electronics, lethality, command and control, design, and manufacturing into any phase of a system. These activities support numerous ATDs and AWEs.

TARDEC VIRTUAL PROTOTYPING LABORATORIES

Vetronics Simulation and Integration Laboratories
Survivability Technology Laboratory
Virtual Mockup Facility
Software Engineering Laboratory
Signature Laboratory
Applied Engineering Laboratory
Physical Simulation Laboratory
Armor Integration Laboratory

2 Facility Consolidation

Major S&T elements in ARL and RDEC activities are also consolidated for efficiency and to accommodate BRAC decisions. Five areas of the disestablished Belvoir RDEC have been reassigned to TARDEC and about half have been relocated to Warren, MI.

3 Facility Modernization

Changes in technology and its application to solving Army problems make it necessary to upgrade S&T facilities.

ARL's Rodman Materials Research Laboratory (Figure F–4) opened in 1998. It is one of the world's largest and best-equipped materials research facilities. It contains 125,000 net square feet of laboratory space and 38,000 net square feet of state-of-the-art laboratory facilities. The laboratory provides modern capabilities for metallurgy and surface sciences, corrosion science, and research in high-performance ceramics, polymers, elastomers, composites, and special organic materials. In weapons and materials research, ARL is providing science and advanced, lightweight technology that make the individual soldier and the Army's future weapons systems more strategically deployable, sustainable, survivable, and lethal.

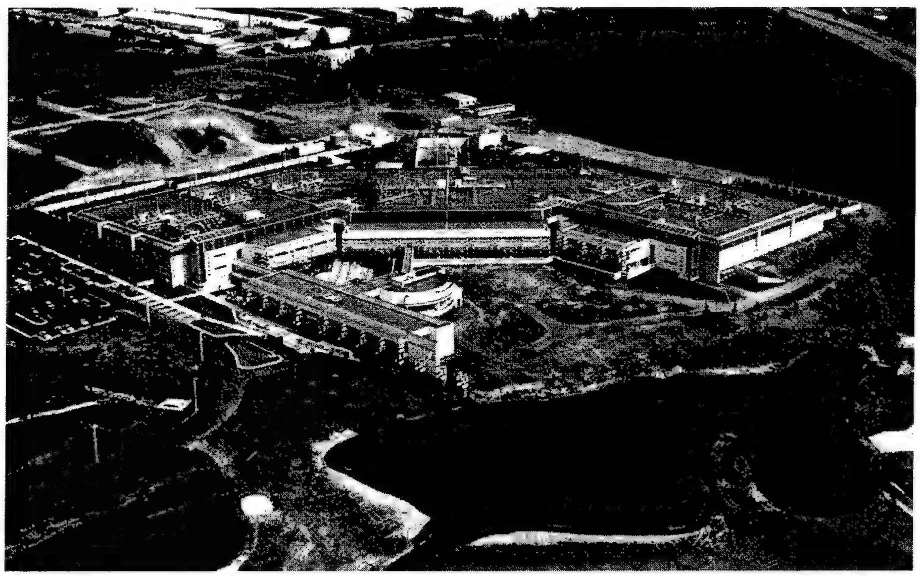


FIGURE F–4. ARL RODMAN MATERIAL SCIENCES LABORATORY, ABERDEEN PROVING GROUND, MD

A new laboratory for the Walter Reed Army Institute of Research (WRAIR) was completed and dedicated in 1999, and relocation of personnel from old facilities will be completed by the end of 2000. The new facility, which is planned for a staff of 850, will house the medical R&D missions of both WRAIR and the Naval Medical Research Institute. It is located at the Forest Glen section of the Walter Reed Army Medical Center in Silver Spring, MD. Locating the laboratory there allows it to be about 20 percent smaller than if it had been built elsewhere.

The new building includes a below-ground, self-contained animal facility; three floors above ground for laboratories, offices, and research activities; and a fully filtered, nonrecirculating air system. Laboratories and scientists' offices, combined with a between-floors utility distribution system, provide maximum flexibility to accommodate current and future military medical R&D.

The new laboratory's total area is nearly 10 percent less than the facilities it replaces, but that is offset by an improved floorplan. The space per occupant and construction cost-per-unit area are below national norms. With the opening of the new WRAIR building, military medicine has gained a state-of-the-art medical research facility that will allow DoD to respond to emerging biomedical threats throughout the 21st century.

ARL's new Zahl Physical Sciences Facility (Figure F–5) supports basic research in chemistry, physics, and bioscience. This state-of-the-art complex opened in 1999 and contains 78,000 net square feet of general laboratory space, 6,400 net square feet of clean laboratories, 90,000 net square feet of offices, and 100,650 net square feet of mechanical and electrical space. The facility houses a computer center that provides a central connecting point for ARL's Adelphi Laboratory Center to tie into the high-performance and simulation computers at APG. ARL manages one of the largest high-performance computing facilities in the world, providing the DoD R&D community increased computational and networking capabilities—battlefield simulation, modeling of advanced weapon systems, and weapon system design and development.

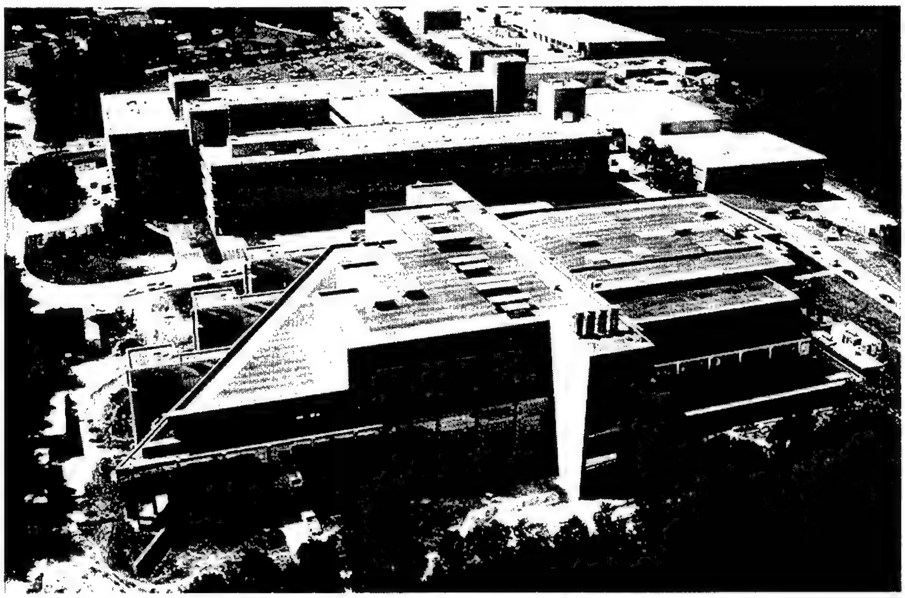


FIGURE F–5. ARL ZAHL PHYSICAL SCIENCE LABORATORY ADELPHI, MD

The Microscopy Facility located at the Natick Soldier Center (NSC) offers the ability to optically analyze materials using scanning electron microscope technologies. This facility has been upgraded with an environmental scanning microscope that allows evaluation of uncoated samples, wet samples, and samples under stress and strain and at various temperatures. The Design and Computerized Facility at NRDEC, also upgraded, can design and fabricate clothing and individual equipment prototypes and furnish the data via telecommunications and diskettes.

Construction of a ballistic experimentation facility began in FY99. This facility will add the capability to perform myriad experiments for developing improved ballistic protective material systems allowing for extensive research into the behavior of materials during ballistic impacts.

The JPS and the IEC at the Corps of Engineers R&D Center's TEC site uses wideband and tactical communications links during live and simulated exercises to support Army precision strike training, contingency planning, and rapid visualization experimentation. IEC provides control, data collection, environment and system simulation, and presentation and visualization support for JPS, and acts as the central hub of the demonstration network. As a result of demonstrations in IEC, the Rapid Terrain Visualization Advanced Concept Technology Demonstration (ACTD), the Rapid/Counter Multiple Rocket Launcher ACTD, and the Theater Precision Strike Operations ACTD were developed.

4 Strategy for Facility Upgrades

Upgrading S&T facilities requires a judicious mix of renovation and new construction to ensure that the best use is made of facility funds. As yearly plans are prepared, existing facilities are examined to determine if extensive modifications are required to carry out future plans. An early decision must be made between renovation, which takes a portion of the existing plant out of operation for a period of time, and new construction. The review process involves a number of agencies to ensure that all factors are considered:

- Can the activity be relocated to other space available at a lower cost than new construction?
- Can the task be passed to another S&T organization that has the manpower skills and space to perform the work under a cooperative memorandum of understanding?
- Can government elements outside DoD perform the work in lieu of expanding an Army facility?
- Would the effort be better performed outside the government in a federally funded research and development center or industry?

5 ARL and the Federated Laboratory Concept

In FY95, ARL instituted the FedLab concept, a unique combination of the best features of the governmental and the private sectors. Chapter V, Volume I, provides more detail on FedLabs. ARL also provides technical and contractual oversight for the Army HPC Research Center at the University of Minnesota, which is assisted by Purdue, Howard, and Jackson State Universities.

6 Shared Facilities

The Army makes extensive use of facilities controlled by other government organizations. Following are a few examples.

Facilities Shared With the National Aeronautics and Space Administration. The Army has collaborated with NASA for 20 years in crash damage simulation, testing, and evaluation. Flight dynamics, handling qualities, and crewstation design human factors are studied by NASA and Army scientists at the Ames Research Center. The CECOM RDEC Command and Control Systems Integration Directorate and NASA have formed a joint research project office at NASA in Langley, VA. The Army and NASA are working on controls and displays, primarily for aviation, but with applications to all platforms.

Army Collaboration With Academia. The Armaments RDEC (ARDEC) has developed an in-house electric gun facility—the Electric Armaments Research Center (EARC) (Figure F–6). The Institute for Advanced Technology was established at the University of Texas with a research capability in electromechanics and hypervelocity physics. The center has collaborated with facilities at the University of Texas at Austin, EARC, and Defense Threat Reduction Agency's (DTRA's) Green Farm Test Facility. After laboratory tests and development,

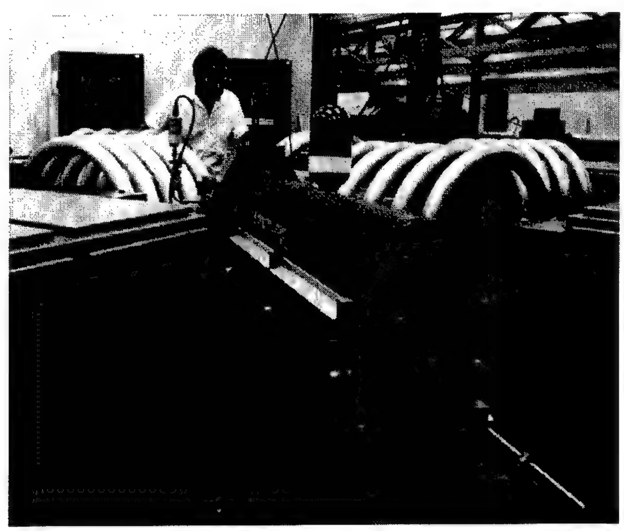


FIGURE F–6. ELECTRIC GUN CONCEPTS ARE EVALUATED USING UNIQUE ARMAMENT TEST FACILITIES

the electric gun will be range tested at the new electric gun test facility at Yuma Proving Ground.

The High-Energy Laser System Test Facility, managed by SMDC, is a tri-service facility with the Navy and Air Force. The sea lite beam director is the only one capable of transmitting a high-energy laser beam, and provides extremely high pointing and tracking accuracies for near-Earth-orbit object tracking.

7 Ranges

As environmental issues become more prominent, M&S consumes a larger portion of the S&T budget, but some range testing must precede development. One S&T range is the large blast thermal simulator being built by DTRA at WSMR for testing combined thermal radiation and air blast nuclear weapons effects. This facility is the result of a cooperative program between the Army and the Defense Nuclear Agency. ARL recently completed a test range facility for advanced aerospace vulnerability. It is an aircraft and missile lethality and vulnerability test facility. It is particularly well suited for congressionally mandated live-fire tests of Army aircraft, missiles, and antiair weapons.

Kwajalein Missile Range (KMR), Marshall Islands, Pacific, is a major range and test facility base managed by SMDC for DoD. KMR supports strategic and theater missile defense research and technology validation programs for the Army and the Ballistic Missile Defense Office, as well as strategic offensive weapons system development and operational testing conducted by the Air Force and Navy. KMR assists in tracking and monitoring NASA space missions and provides deep-space tracking for the U.S. Space Command.

The Army Missile Optical Range at the Aviation and Missile Command (AMCOM) supports laser and laser radar measurements of selected material targets.

8 Specialized Equipment

The Army has invested substantially in sophisticated special-purpose items, such as those described below.

Several Army laboratories and centers have molecular beam epitaxy equipment to grow new semiconductor device structures with atomic dimensions. This technology applies to electro-optical (EO) sensor materials with higher resolution and greater sensitivity, and signal processing devices with higher speed and greater throughput capability.

ECBC has a scanner and a laser alignment system to generate a 3D, digitized surface contour of a human head. Data can be transferred to a numerical control cutting machine to generate a model of a head. This is used for anthropomorphic assessments related to developing chemical and biological respirators.

The Defense Advanced Research Projects Agency (DARPA) Synthetic Theater of War (STOW) Synthetic Environment Evaluation and Demonstration Site (SEEDS) at TEC in Alexandria, VA, provides state-of-the-art systems for the integration, test, evaluation, and demonstration of cutting-edge synthetic environment technologies, including offline source data request and transfer; terrain and environmental database generation and integration; environmental data inspection and visualization; and dynamic terrain environment, atmosphere, and ocean integration.

SEEDS served as a node on both the Defense Simulation Internet and the asynchronous transfer mode-based ATD Network during the STOW ACTD development. The computational capabilities of SEEDS include several Silicon Graphics and personal computer workstations. The basic M&S applications that are used in SEEDS are ModSAF, ModStealth, and Soundstorm. These applications serve as the building blocks for the development of the capabilities that the synthetic environments program contributed to the STOW ACTD, which are dynamic environmental effects, dynamic terrain, and the atmosphere and ocean server. In addition, SEEDS is the primary evaluation facility for the terrain and environmental databases used for the STOW ACTD and other programs.

As part of the Strategic Environmental Research and Development Program (SERDP), joint research is being conducted with the Environmental Protection Agency (EPA) and Department of Energy (DOE) on a multitude of environmental topics. For example, a national environmental technology test site program, managed jointly by the Army, Navy, and Air Force, has been developed to demonstrate, evaluate, and transfer innovative cleanup technologies from R&D to full-scale use. Another example is the partnering between the Army, other services, DOE, and EPA for the development and fielding of a site characterization and analysis penetrometer system—a system used for site characterization in DoD's cleanup program. Each organization has a defined area of responsibility, thereby maximizing use of limited funds for addressing common DoD cleanup problems. A joint program under SERDP has also been initiated with EPA and DOE in development of a groundwater modeling system for contaminated site cleanup.

The DoD S&T strategy continues to place strong emphasis on "synthetic environments," but significant changes have occurred in the M&S community over the past 2 years. The standards for DoD's common technical framework, most notably the simulation of HLA, began supplanting the distributed interactive standards for interoperability.

Synthetic environments bring developers, scientists, engineers, manufacturers, testers, analysts, and warfighters together to address and solve their most pressing problems. Current capabilities support S&T demonstrations and capabilities for Training and Doctrine Command (TRADOC) battle labs. Experience gained from these activities evolve into new methodologies for evaluation and evolution of concepts and requirements in a joint task force and combined arms battlefield with soldiers in the loop. Advances in creating common synthetic environments are coordinated through STRICOM.

Seamless synthetic environments are achieved through the integration of M&S techniques, technology, capabilities, and processes. Through the design and analysis of concepts in controlled synthetic environments, ADS offers increased savings in time and money by reducing the need for expensive mockups and field testing. Synthetic environments enhance the possibilities for exploring design options in full battlefield context, allowing workers to design and assess concepts that could not be explored using traditional approaches because of safety, environmental, and cost considerations. ADS can be used Army-wide to accelerate research and to bring advances in technology to the field in a timely fashion, helping to ensure technological superiority on the battlefield.

9 Three Integral Components

The Defense Science Board (DSB) task force on simulation, readiness, and prototyping defines simulation as "everything except combat," with three integral components: (1) live operations with real equipment in the field; (2) constructive wargames, models, and analytical tools; and

(3) virtual systems and troops in simulators fighting on synthetic battlefields. Although the first two components are technically mature, the virtual component is evolving. Virtual capability is improving through technology advances in HPC, communication, artificial intelligence, and synthetic environment realization. The long-term objective of the synthetic environment concept is to develop and implement a single, comprehensive environment for operational and technical simulation. The synthetic environment is designed to support combat development, system acquisition, test and evaluation (T&E), operational T&E, training, mission planning, and rehearsal in Army-specific and joint operations.

10 Approach

The Army has several forums to assist with implementing the above goals. These include the TRADOC battle labs, the Army M&S General Officer Steering Committee (AMS GOSC), STRICOM, and the Army research laboratories' ISTD.

TRADOC is the Army's ADS functional manager and is responsible for the Army-wide integration of ADS requirements, the ADS master plan, advocacy of ADS verification and validation, and prioritization of the scheduling of ADS facilities.

STRICOM is the Army's technical agent for ADS technology development and network management. STRICOM activities include R&D; procurement; and support of simulators, simulations, and training devices. It also has the DoD lead responsibility for ADS-related standards and protocols and coordination with industry.

The Army established the AMS GOSC to provide the Army M&S vision and to act as final adjudicator of Army M&S Executive Committee (AMSEC) issues and as the approval authority for the *Army Model and Simulation Master Plan* and the *Army Modeling and Simulation Investment Plan*. It is co-chaired by the Vice Chief of Staff of the Army and the Army Acquisition Executive. AMSEC is co-chaired by the Deputy Under Secretary of the Army for Operations Research and the Deputy Chief of Staff for Operations and Plans. AMSEC provides overall management and has established two working groups: the Requirements Integration Working Group and the Army M&S Management Program Working Group. Both working groups are chaired by the Army M&S Office, which is charged with developing an integrated investment strategy across the three M&S domains: (1) advanced concepts and requirements (ACRs); (2) research, development, and acquisition (RDA); and (3) training, exercises, and military operations (TEMO). Each has a domain manager at the Department of the Army headquarters level and a domain agent at the major command level (TRADOC for ACR and TEMO; the Army Materiel Command for RDA). Management and investment plans are prepared for each domain.

The initiatives to simulate the battlefield are developing a distributed simulation capability linking government, university, and industry sites into an accredited, real-time, warfighter-in-the-loop simulation of the joint and combined battlefield. Manned simulators on the network embody the operational characteristics of the systems they represent. This simulation includes an evolutionary process and strategy to systematically develop, maintain, and use technologies and associated hardware and software to achieve the long-term objective of synthetic environment. This program continually exploits advances from national ADS S&T developments. The Army program is focused on technology development for:

- Army-specific requirements to ensure their timely availability to be placed in simulation applications.

- The electronic battlefield of tomorrow, where advanced, interoperable, distributed simulations—live, constructive, virtual—at geographically separated locations are connected in order to cooperatively form highly realistic synthetic environments.

B MODELING, SIMULATION, SOFTWARE, AND TESTBEDS

As the Army undergoes a wholesale transformation, it will be incumbent in the M&S community to provide the tools that will allow complex analysis, concept exploration, virtual prototyping, and test and evaluation. The Army must identify the critical requirements that allow software and hardware developers enough time to develop the tools that will be needed in the future. This necessitates a cooperation and collaboration in milestone development between engineers and scientists and technologists. The Army Model and Simulation Office (AMSO) has the charter to guide the S&T community in the use of M&S tools and to prevent the redundant development of similar M&S tools. The Army must introduce M&S technologies to develop the constructive and virtual simulations and simulators required to support unit collective and battle staff training and mission rehearsals. M&S tools must be developed to analyze and justify Army training requirements and assess the worth of concepts and alternative approaches to satisfy the requirements for the Objective Force and Joint Vision 2020. The Army must align training modernization efforts in simulations with transformation plans to ensure that commanders maintain training proficiency as the Army modernizes the force. Finally, the Army must eliminate duplication of effort in M&S technology.

To accomplish these challenges, a standardized synthetic environment must be developed that supports Army-wide M&S applications for staff training, mission rehearsal, and exercises for corps and below as appropriate. With a finite and shrinking budget, each agency and engineering center cannot afford to develop its own synthetic environment. The soldier is the customer, ultimately, and the Army will need to widely distribute the use of M&S for training. As Figure F–7 depicts, with shrinking budgets, shrinking training areas, and increasing environmental concerns, a great deal of training must be accomplished in a constructive and virtual environ-

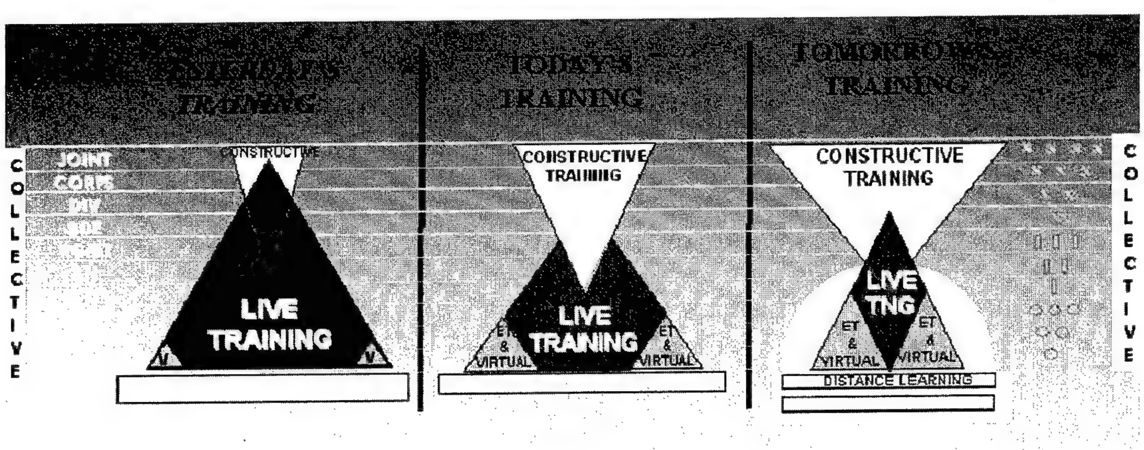


FIGURE F–7. INCREASING RELIANCE ON SYNTHETIC TRAINING

ment. The S&T and M&S communities must stay ahead of the pace of the technology advances and leverage advances in computer simulation technologies. This is possible through the design and construction of simulations operations officer leader development action plans and life-cycle development models to meet overall Army requirements and objectives.

Even though the Army transformation is in its infancy, key M&S areas are lagging in the development process for assisting the logistics, intelligence, communications, command and control, operational, and other communities that have a significant impact in the transformation to an Objective Force. The Army and other services must work together to develop set standards for object representation. Ultimately, an architecture framework must be developed for analysis, design, training, testing, and concept exploration and industry must be allowed to develop object models that will interface with developed and acquired systems.

To accomplish a collaborative and cooperative S&T and M&S evolution, the Army must transform its culture and produce an educated core of simulationist that understand the requirements of the Army. The Functional Area 57 (Simulation Operations) Officers Specialty and the Simulation and Modeling for Acquisitions, Requirements, and Training (SMART) are two programs that ASMO is responsible for their execution.

The essence of (SMART is encapsulated in the vision that the Army "be a world leader in M&S to continuously improve Army effectiveness through a disciplined, collaborative environment in partnership with industry, government and academia" (SMART Strategic Planning Workshop, August 30, 1999). SMART is the Army's concept for using M&S to improve effectiveness and efficiency in determining requirements; evaluating technology and concepts; designing forces; developing tactics, techniques and procedures (TTPs); developing and designing systems; testing and evaluating systems; evaluating supportability and affordability; training; and planning and preparing for military operations.

SMART is a framework to accomplish the vision of a disciplined, collaborative environment to reduce costs and time of providing solutions for Army needs. Key components are the ability to exchange data, algorithms, software, and other information. When executed in accordance with these concepts, SMART is expected to yield four significant benefits that are of paramount importance to the Army transformation:

- Reduced total ownership costs and sustainment burden for fielded systems throughout their service lives.
- Reduced time to explore concepts and develop and field new or upgraded systems.
- Increased military worth of fielded systems while simultaneously optimizing force structure, doctrine, tactics, techniques, and procedures.
- Concurrent fielding of systems with their training devices.

SMART envisions using M&S tools and technologies to analyze a wide range of alternatives. Harnessing M&S to adapt to changing circumstances and emerging technologies will provide leap-ahead combat effectiveness. Employing M&S as the prototyping media for depicting concepts and designs provides a blueprint that can be visualized, exercised, analyzed, discussed, and changed so that viable solutions become apparent to all stakeholders.

SMART also provides the medium for dialog between user and developer that must take place to assess proposed solutions in the context of force structure, doctrine, tactics, deployability, operational tempo, logistics, and soldier-machine interface. Because of the characteristics of

digital media, prototype iterations can be saved, altered, deleted, expanded, modified, and re-used as the occasion demands. This allows for maximum flexibility to explore alternatives in support of decision processes to modernize the Army.

ARL actively supports the SMART vision. A successful implementation of SMART requires extensive collaboration not only internally among the various ARL elements, but also across Army and even DoD organizations. Fortunately, advances in networking computers have facilitated the establishment of distributed federations of M&S that can be used together to establish this collaboration to solve more Army problems. ARL, STRICOM, and AMC RDECs are building one of the first such large M&S federations. The current milestones call for it to be ready in time to support some phases of the FCS program. ARL is providing M&S technologies such the HLA Bootstrapper, HLA Data Logger, a Dismounted Infantry Simulation, and a Lethality Server to the federation in the short term. Longer term, ARL intends to bring a second-generation vulnerability/lethality server, human factors models, HPC assets, possibly robotics and urban warfare models, and enhanced versions of the above HLA software to the federation. The federation will provide the capability to test new technologies in a high-resolution, collaborative, virtual world with the appropriate force-level operational context.

Since 1997, the Army has taken steps to define, promulgate, and implement the SMART concept. Efforts must continue to engage the Army as well as industry and academia.

Advances in computer technology have allowed Army engineers and scientists to make increasing use of models, simulations, and testbeds to save money. Hardware procurement is eliminated because the needed information can be obtained through simulation. Testbeds are a cost-effective way to conduct R&D in support of Army programs. In addition, environmental impacts such as noise and pollutants generated during physical trial-and-error evaluation are eliminated. The following sections discuss computer M&S, software technology, physical simulation, hardware-in-the-loop (HITL) simulation, combined arms battlefield soldier-in-the-loop simulation, testbeds, and T&E simulation.

1 Computer Modeling and Simulation

Computer M&S can generate images of complex data and evaluate experimental conditions and approaches. Visualization techniques used with complex modeling permit scientists and engineers to exploit new concepts without developing costly prototypes. Computer M&S is applicable to a wide range of technical disciplines as illustrated below.

Human Factors Modeling. ARL's human performance model program uses JACK, a 3D model developed by the University of Pennsylvania. JACK is used in the Aviation and Missile RDEC's (AMRDEC's) A31 (Army–NASA Aircrew and Aircraft Integration) program aimed at producing software tools and methods to improve the human engineering design process for advanced technology crewstations. This approach allows variations of mission procedures and cockpit equipment to be explored rapidly prior to committing a design to an expensive hardware simulator.

Armor and Projectile Modeling. High-speed, large-memory supercomputers have greatly enhanced capabilities in modeling new armor concepts and advanced projectile technology. Recent large-scale simulations have provided insight into the potential benefits of advanced high-velocity projectiles.

Environmental Modeling. Army tactical operations must take into account their environments. Digital terrain information and atmospheric information are used in wargames and simulations to determine the outcome of changes in tactics and introduction of new equipment. Climate databases provide realism by projecting different weather conditions into a simulated theater of operations. Weapon systems are evaluated for effectiveness, taking into consideration target detection probabilities based on climate and terrain masking.

Weapons and Fire Control Modeling. ARDEC at Picatinny Arsenal, NJ, has established an ADS node to demonstrate how technology, weapons, and weapon mixes can be used to maximize the effectiveness of the soldier.

Soldier System Modeling. NSC's soldier system modeling program builds on existing and emerging engineering-level algorithms and data to create a high-fidelity, HLA-compliant, force-on-force simulation environment that supports examining the effects of proposed changes in individual soldier clothing, weapon, equipment components, and characteristics on individual and small-unit performance and survivability. This integrated simulation environment (Figure F–8) will provide a verified and validated virtual testing and experimentation suite that allows soldier clothing and equipment designers to explore alternative designs, materials, and applications without the need to build large numbers of prototype items for testing. Designers will also be able to accomplish virtual testing of their proposed items under battlefield environments that

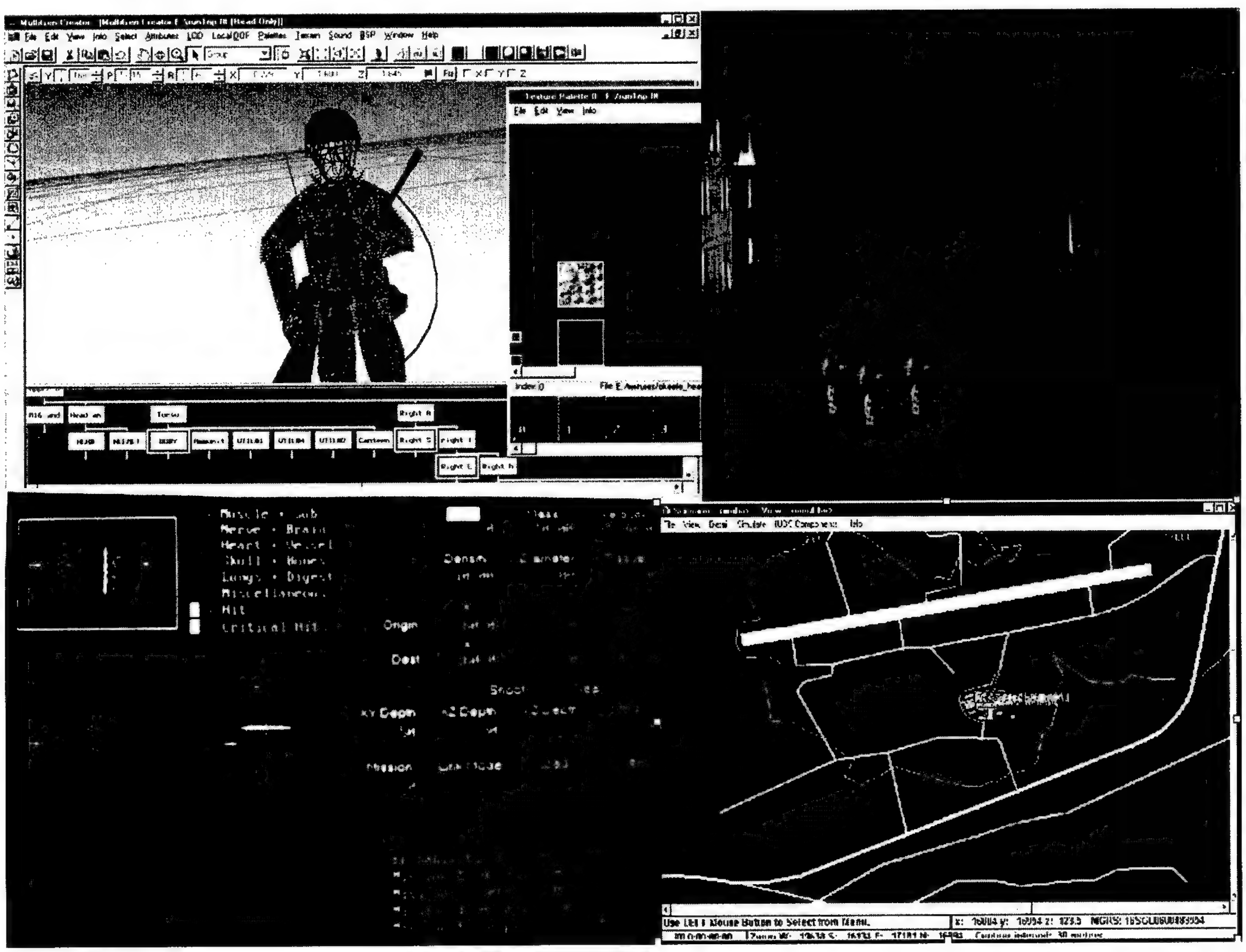


FIGURE F–8. NSC'S SOLDIER SYSTEM MODEL

are not available during peacetime. The integrated simulation environment is supported by an infrastructure that provides the required high-resolution terrain, environmental, material characteristics, and weapon performance databases for effectively supporting acquisition programs.

ARL contributes to Army M&S in two primary ways: by providing expertise on the content (the science represented) in the M&S and by providing many of the tools (the enabling technologies) that make efficient and effective M&S easier to develop and use. ARL's vision is to provide the science and enabling technologies underpinning M&S not only for the current Army transformation (including the FCS), but also for comparable revolutionary changes into the indefinite future.

The two thrust areas will be realized through the accomplishment of the following list (illustrative, not exhaustive) of initiatives:

- Develop and improve M&S via ARL internal and collaborative projects:
  - ARL internal projects
  - Maximized leverage of DoD and Army M&S resources
  - Collaborative programs with industry, academia, and other government laboratories
- Improve enabling technologies for M&S through internal and collaborative research:
  - Networking
  - Visualization
  - Statistical methods for M&S verification and validation
  - Software technologies (e.g., data logger, bootstrapper)
- Leading role in M&S Standards processes
- Active participation in SMART/SBA:
  - AMC R&D M&S federation
  - Army/NASA partnership
  - Institute for Creative Technology

ARL M&S THRUSTS

Scientific knowledge **appropriate for each class of Army M&S:**

State-of-the-art models of relevant physical phenomena and human factors

The most accurate available data on physical phenomena and human factors

Realistic synthetic environments for high-resolution M&S in RDA domain (and in other domains as needed

Enabling technology **to facilitate efficient and effective development and maintenance of state-of-the-art M&S**

Improved M&S tools and techniques through research in mathematics and computer science

Optimal exploitation of HPC assets and related application techniques

2 Software Technology

DARPA is the sponsor of the Software Technology for Adaptable, Reliable Systems (STARS) program to increase software productivity, reliability, and quality through the adoption of a new software engineering paradigm called "megaprogramming." STARS is sponsoring megaprogramming demonstration projects on DoD systems within each of the services. These demonstration projects help quantify the benefits of megaprogramming and illustrate the issues involved in transitioning to this paradigm.

The Communications–Electronics RDEC has developed the STARS Laboratory to support the development of domain models, architectures, and reusable assets. The software engineering environment is also used to reengineer C^4I weapon system software to include the integration of domain architectures and assets in the application software.

3 Physical Simulation

Physical simulations are used in Army research to emulate real-time physical motions of active systems in the field. In many situations, computer-generated models and simulation systems can interact with physical simulations to greatly reduce the need for costly and time-consuming field tests of prototypes. Following are examples of advanced physical simulation facilities operated with computer-generated models or simulation systems.

The Crewstation/Turret Motion Base Simulator (CS/TMBS) is a full six-degrees-of-freedom (DOF) laboratory simulator with high-performance capabilities. It can impart a maximum of 6-g acceleration to a combat vehicle turret weighing up to 25 tons; and replicate, via computer control, motions and vibrations that would be encountered while traveling over rough terrain. This simulator at TARDEC is man-rated and approved for occupancy by a crew. The CS/TMBS plays an important role in turret system development, characterization, and virtual prototyping activities in a variety of combat vehicle programs.

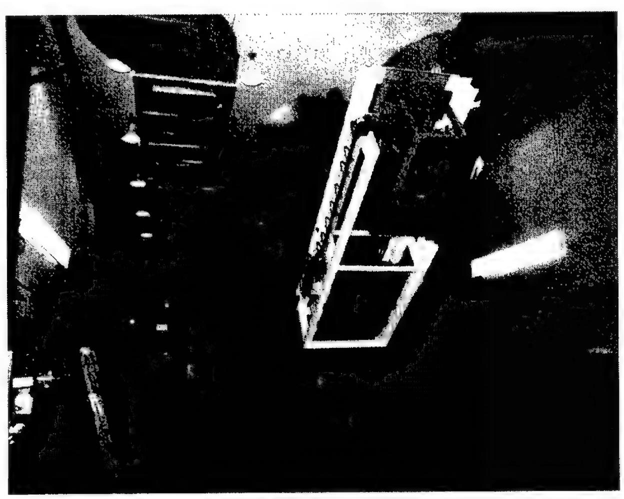
Among the advantages of human-in-the-loop tests in the laboratory are close control of parameters and exact repeatability of tests for comparing the effect on different components.

The AMRDEC Crewstation Research and Development Facility (CSRDF) supports the evaluation of new concepts for human–system interactions for advanced rotorcraft. Effects of malfunctions, automation alternatives, and mission equipment tradeoffs can be conducted in this synthetic environment of 3D visuals, sounds, and tactile stimuli. The degree of realism achieved in such systems can best be appreciated by seeing a pilot emerge from a laboratory "flight" showing perspiration and other signs of stress. The aviation testbed at Fort Rucker and CSRDF have been linked to support the future Army's objectives and are being extended to include Tank–Automotive and Armaments Command, line-of-sight antitank, and Sikorsky Comanche simulators.

CECOM's Night Vision and Electronic Sensors Directorate has developed a facility to support the development and testing of integrated aircraft and ground vehicle sensors and CM. The multispectral environmental generator and chamber provides 360-degree radar frequency, laser, infrared, and ultraviolet simulation of air defense radars, surface-to-air missiles, top-attack smart munitions, and laser threats. Varied individual and integrated protection equipment is used to simulate ground vehicle and aircraft attitudes.

4 Hardware-in-the-Loop Simulation

HITL simulations test types of systems using real hardware and computer simulations, providing a significant return on investment for the Army. One example of HITL simulation is ARDEC's Ware Simulation Center located at Rock Island Arsenal, IL (Figure F–9). This simulator provides a realistic emulation of the field environment that an armament system will encounter.



The center's 6-DOF mount allows conceptual and fielded weapons to be fired in realistic mounting environments under controlled laboratory conditions to isolate design deficiencies.

FIGURE F–9. ARDEC'S WARE SIMULATION CENTER

The facility can test weapons using up to 30-mm live or 40-mm inert ammunition. In addition, the facility's 6-DOF simulator is a large mount capable of holding weapons, gun turrets, and vehicle sections weighing up to 10,000 pounds. Programmed vibrations as well as pitch and yaw motions may be applied to the attached loads while the weapons are test fired in the indoor range.

The AMCOM Open-Loop Tracking Complex, a computer-automated electro-optical countermeasures simulation facility, provides EW analysts with the tools for evaluating the performance and effectiveness of EO air defense missile systems and guidance assembly hardware in the presence of CM.

CECOM has implemented the Army Interoperability Network (AIN), a nationwide suite of distributed communications capabilities and services to support interoperability and software development for Army C^4I systems throughout their life cycles. The AIN provides the Army infrastructure for C^4I systems to achieve the objectives of the Army Enterprise Strategy (i.e., battlefield digitization and C^4I for the warrior). The AIN provides rapid engineering support solutions that replicate battlefield configurations by networking dispersed fielded C^4I systems. Current AIN major operational equipment includes the AIN Central Control Facility, Protocol Assessment Facility, four sites at Fort Monmouth, and remote sites at Fort Leavenworth, Fort Sill, and Fort Huachuca. A remote site is planned for the Program Executive Office-Ground Combat and Support Systems at General Dynamics Land Systems, Warren, MI. A transportable AIN node is available to provide quick-reaction AIN access in situations requiring rapid test support. The AIN is the Army's infrastructure for linking battle labs with RDECs.

5 Imagery and Geospatial Research and Development Testbed

As the Army moves toward achieving the goals of *Joint Vision 2010* and the Objective Force, digital imagery and geospatial data will play increasingly important roles in realizing true information dominance. The Army's ERDC has established an imagery and geospatial R&D testbed designed to receive, process, exploit, and disseminate both commercial and national imagery and geospatial products. Equipped with myriad land-based and tactical communication channels and being proximate to operational users within ERDC, this testbed is uniquely positioned to conduct R&D experiments and concept evaluations; support technology developments; and investigate new tactics, techniques, and procedures in parallel until the technologies reach their maturity. The Army is faced with decreasing numbers of imagery and terrain analysts while the demand for exploited information is increasing because of the size and agility of future enemies. This testbed provides the Army with a capability to design and conduct experiments evaluating technologies to receive, process, analyze, and disseminate imagery, geospatial data, and derived products in tactically meaningful timelines.

6 Test and Evaluation Simulation

Technological progress must be complemented by test and instrumentation facilities, including T&E simulation, that can measure the technological progress being achieved. Environmental and safety concerns increasingly impose constraints on T&E facilities. The ability to simulate the physical conditions of the battlefield for T&E reduces the time to obtain data and cost. Bringing the test environment under laboratory control provides high-quality, reproducible data that can be recorded and analyzed during the test process.

C INFORMATION TECHNOLOGY AND COMMUNICATIONS

To speed information transfer within the S&T community, substantial improvements have been made in the supporting communications infrastructure. The explosive growth of microcomputers, software applications, and networking has permitted more effective use of information in the management of S&T. Reengineering of workflows will be possible when information is shared concurrently among organizations, permitting speedy delivery of higher quality products.

The JPS IEC at the ERDC/TEC, Alexandria, VA, uses state-of-the-art commercial wideband and tactical communications links to provide connectivity with live exercise activity and distributed simulation, training, and contingency planning. The IEC provides exercise control, data collection and analysis, environment and system simulation, and presentation and visualization for JPS exercises. It acts as the central hub of the demonstration network, which includes links to several DoD and service facilities (e.g., Depth and Simultaneous Attack Battle Lab, BCBL–Huachuca, DARPA, III Corps, Naval Surface Weapons Center, SMDC).

D PERSONNEL

Approximately 22,000 in-house personnel support the Army R&D mission. Working with a diversified set of physical resources that range from solid-state physics laboratories to outdoor experimental ranges, these personnel conduct research, technology, and product support activities for the Army in medicine, the life sciences, psychology, physics, engineering, and numerous other fields of science. Microelectronics, fluidics, and digital computing are only three examples of technologies in which major advances have sprung from Army in-house organizations.

To enhance management of the acquisition fruits of the S&T process, an Army Acquisition Corps has been established, composed of career professionals. Persons committed to this specialized career field are offered significant educational opportunities to enhance their professionalism.

Demographic projections for college graduates indicate a declining number of engineers and scientists. To address this national issue, the Army is developing a comprehensive set of policies and plans to recruit, train, and retain scientists and engineers. These policies include the selective use of demonstration programs to enhance recruitment, the proper use of long-term fellowships for graduate degrees, and the placement of individuals in laboratories for hands-on work assignments. Retention is a major issue since technical personnel often leave for the higher salaries paid by industry and academia.

These demonstrations are the first major changes to improve the personnel systems specifically tailored to Army laboratories. Waivers were submitted to Title V law in hiring flexibility, broadbanding and classification, pay for performance, automated job classification, and expanded developmental opportunities. These changes to Title V, as well as to DoD and Department of the Army personnel policies, will allow the Army laboratories greater flexibility and authority to manage and improve staffs. The demonstrations go far in answering the criticisms from the DSB and others that the current system is too slow, puts up administrative barriers, and is impossible to change.

The Army is investing in its supporting infrastructure to maintain world-class S&T capabilities that will meet future Army needs. The Army will continue to use leveraging strategies wherever possible to interface effectively with other governmental bodies, industry, and academia.

Simulation investments discussed in previous editions of this plan are emerging at just the right time to support the needs of planners and operators faced with a base-deployed, downsized Army. This investment is meeting the needs of the TRADOC battle labs for planning the Army of the future and providing the materiel developers with the tools to demonstrate new technologies and operating capabilities more cost-effectively than has heretofore been available.

ANNEX

G MANUFACTURING TECHNOLOGY (ManTech)

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ANNEX

G MANUFACTURING TECHNOLOGY (ManTech)

The Army's Manufacturing Technology (ManTech) program supports force modernization and readiness by focusing on affordability through manufacturing cost reduction, achievement of large savings in manufacturing design and fabrication lead times, reduction of scrap and rework costs through integrated design and manufacturing approaches, and streamlined production management. In particular, emphasis is placed on speeding the transition of leading-edge technologies—such as advanced composite materials, metals, and complex electronic systems—out of the laboratory and into current and future weapon systems using the latest in manufacturing techniques and processes.

Technology Staff Officer (all MTOs)

Dr. Robert Rohde
SAAL–TR
(703) 601–1515
DSN 329–1515

The Army ManTech strategy focuses on a number of Manufacturing Technology Objectives (MTOs) and Manufacturing Demonstrations (MDs) describing general and specific manufacturing technologies. Some programs are congressionally directed. MTOs are large projects, scheduled to be completed in 3 to 5 years and funded at $1 to $3 million annually; MDs are smaller projects, scheduled for 1 to 3 years, and funded at $0.3 to $1 million annually. Both must have specific customers (program managers) and must support Army needs and DoD technology objectives. To be a candidate for MTO or MD funding, a technology must be mature and have demonstrated scientific validity. MTOs are the equivalent of STOs and ATDs and are, therefore, approved by the Army Science and Technology Working Group (ASTWG).

The Army ManTech program is divided into six subareas—four based on subpanels established under the Joint Defense Manufacturing Technology Panel (JDMTP) and two on working groups that supplement the JDMTP and its subpanels:

- *Energetics and munitions*—focuses on production of energetic materials, including explosives, propellants, and pyrotechnics, and conventional munitions, including load, assemble, and pack operations.
- *Metals processing and manufacturing*—focuses on accurate and repeatable processing of metals and other materials that use the same processes.
- *Composites processing and manufacturing*—focuses on accurate and repeatable processing of composite materials and structures (polymer matrix composites, ceramic matrix composites, metal matrix composites, and carbon matrix composites).
- *Electronics processing and manufacturing*—focuses on accurate and repeatable processing of electronic materials, devices, integrated circuits, subassemblies, and subsystems.
- *Advanced manufacturing enterprise*—focuses on a responsive, world-class manufacturing systems capability to meet the warfighter's needs throughout the defense system life cycle.
- *Sustainment and readiness*—focuses on addressing critical repair and remanufacturing technologies for weapon system applications.

INITIATIVE CODING SYSTEM

The numbering system for each ManTech initiative indicates the command responsible, initiative type, year project began, initiative number, title, and timeframe of the project. Thus, *ARL–MTO–00–03 Optics Manufacturing Technology (FY00–02)* means the Army Research Laboratory has a Manufacturing Technology Objective that began in 2000, was the third initiative, is titled "Optics Manufacturing Technology," and will run from FY2000 through FY2002.

Major subordinate commands or Army organizations with ManTech projects:

AM—Aviation and Missile Command
ARL—Army Research Laboratory
CE—Communications–Electronics Command
HQAMC—Headquarters, Army Materiel Command
SBC—Soldier and Biological Chemical Command
TA—Tank–Automotive and Armaments Command

The three types of ManTech initiatives are MTO – Manufacturing Technology Objective, MD – Manufacturing Demonstrations, and CD – Congressionally Directed.

ENERGETICS AND MUNITIONS

Goals

The energetics and munitions subarea addresses the unique manufacturing processes and problems of the industrial base sector that produces propellants, explosives, pyrotechnics, reactive chemicals, and munitions. ManTech is focusing on the following technology efforts:

- Objective Individual Combat Weapon (OICW)/Objective Crew-Served Weapon (OCSW) (TA–MTO–00–02)
- Munitions Manufacturing Technology (TA–CD–98–02)
- Totally Integrated Munitions Enterprise (TIME) (TA–CD–97–01)

Major Technical Challenges

The major technical challenges involve manufacturing of new or improved energetic materials and other key components used in munitions manufacturing. Emphasis is placed on manufacturing processes necessary to enable safe, environmentally sound, cost-effective manufacturing of munitions and munitions components. Also,, enhanced control of the manufacturing process is required to facilitate real-time correction and reduce or eliminate post-process inspection.

Munitions manufacturing technology and processes are needed to enhance capabilities for tantalum explosively formed penetrators, tungsten warheads, composites for munitions, and kinetic-energy (KE) rounds. Munitions manufacturing technologies are also required to meet the needs of the Army's Future Combat Systems (FCS).

TA–MTO–00–02 Objective Individual Combat Weapon/Objective Crew-Served Weapon (OICW/OCSW)(FY00–02). The objective is to develop and demonstrate manufacturing technologies and processes that will reduce the cost of OICW bursting munitions by approximately $7.67 per round and OCSW by approximately $2.52 per round. This MTO will complete the work begun under the OICW tungsten warhead and fuze ManTech programs. Under the warhead effort, a powdered metal (PM) manufacturing process has been developed and demonstrated for a generic OICW tungsten warhead and then adapted to the ATK (Alliant TechSystems) warhead.

Continued work is required to improve on the PM process and to increase fragmentation. Circuit board fabrication processes have also been evaluated to enhance reliability and eliminate the need for potting of the boards.

Technologies to be developed include blank, cup, and draw of embossed steel discs for the 20- and 25-mm warheads; PM forming techniques for the 20-mm tungsten warhead; and miniaturized electronics manufacture and assembly methods for the fuze. Some of these technologies already have military applications that can be adapted to the OICW/OCSW munitions (PM tungsten warhead). Other technologies have commercial applications but need to be "hardened" to survive ballistic launch and be integrated into the OICW/OCSW designs (chip on chip, miniaturized circuit, and application-specific integrated circuit (ASIC)). *Project Manager:* Edward J. Rempfer, AMSTA–AR–CCL–B, (973) 724–7036, DSN 880–7036.

TA–CD–98–02 Munitions Manufacturing Technology (FY98–01). Munitions manufacturing technology processes and technologies will be developed and demonstrated to enhance capabilities in areas such as the manufacture of tantalum explosively formed penetrators, tungsten warheads, composites for munitions, and KE rounds. This congressionally directed ManTech initiative is aimed at supporting both legacy and emerging needs. Benefits to be derived include not only cost avoidance in the procurement of energetic materials and munitions, but enhanced operational safety, improved environmental compliance, and the ability to produce materiel to meet the needs of FCS.

Manufacturing of energetic ingredients such as nitrocellulose are antiquated and labor intensive, and efforts are being executed to improve process safety, product quality, and process yield. Other ManTech efforts are being executed to enable production of next-generation energetic materials and munitions components not currently producible within the Army's government-owned, contractor-operated (GOCO) production base. The GOCO base was established in response to WWII and was designed to produce large quantities of materiel. The procurement of energetic materials and munitions has dropped significantly over the last 10 years, and new technologies are required to enable economical production of legacy items as well as new smart munitions. *Project Manager:* Mark Mezger, TACOM–ARDEC, (973) 724–5490, DSN 880–5490.

TA–CD–97–01 Totally Integrated Munitions Enterprise (TIME) (FY97–01). The Army is addressing and reshaping the ammunition manufacturing production base based on the shifts to new paradigms for smart munitions along with Army Policy 98–1, which increases emphasis on the commercial base. Similar to industry initiatives, it is becoming of significance to the Army that capabilities exist for establishing virtual factories through virtual networking computing, both for peacetime production and to meet replenishment requirements. TIME is integral to reshaping the Army's future virtual enterprise.

The TIME architecture encompasses general-purpose, web-based collaborative tools, a unique Open Modular Architecture Control platform for machine control and best available manufacturing commercial systems to enable the Army's virtual munitions enterprise. The architecture includes general-purpose tools and linkages between engineering systems (CAD/CAE/CAM tools); enterprise systems (product data management, material resource planning, enterprise resource planning); and production systems (manufacturing execution systems, shop floor control). These components will interact within a location and across the enterprise on the web or by dedicated networks where provided. *Project Manager:* Larry Laibson/Al Gonsiska, TACOM–ARDEC, (973) 724–2822, DSN 880–2822.

METALS PROCESSING AND MANUFACTURING

Goals

Efforts are aimed at developing, improving, demonstrating, and deploying the manufacturing processes and capabilities needed to produce affordable metals and special materials critical to defense applications. The following technology efforts are being pursued:

- Extension of cannon tube life via deposition of tantalum refractory metal that provides wear resistance eight times greater than that of the current chrome plating process (TA–MTO–00–01).
- Development of optical manufacturing processes to enable affordable fabrication, testing, and assembly of complex optical elements in hard, brittle materials to shapes that conform to the platform on which they will be used (ARL–MTO–00–03).
- Development, implementation, and prove-out of manufacturing processes, inspection, equipment and techniques capable of producing new cannon and reshaping fielded cannon to the optimum bore straightness profile (ARL–MTO–00–05).
- Advanced Thin-Wall Casting Manufacturing Processes (AM–MD–00–05).
- Natural Gas, Engine-Drive Air Compressors (HQAMC–CD–00–01).
- Continuous Manufacturing Technology (ARL–CD–01–01).

Major Technical Challenges

TA–MTO–00–01 Large-Caliber Life Extension Via Tantalum Sputtering (FY00–04). This MTO will develop and demonstrate a manufacturing process for large-caliber cannon life extension via deposition of tantalum refractory metal that provides wear resistance up to eight times that of the current chrome-plating process. The wear life of a chrome-plated tank barrel when firing experimental high-energy ammunition was demonstrated to be severely reduced. A new generation of artillery and tank munitions will be fielded that provide greater range, higher velocity, and greater lethality. The higher energy propellants used in these systems will have greater erosive effects, thus reducing the life of currently configured gun barrels.

Without this MTO, tank and artillery battle effectiveness will be limited not to the lethality of the munitions load, mobility, and other capabilities, but rather to the wear resistance of the gun barrel. The problem must be solved now to ensure that the effectiveness of the future Army's tank and artillery fleet is not severely restricted. In addition, the tantalum process will be free of environmentally hazardous waste. Cost avoidance is estimated to be $97 million. *Project Manager:* Upendra Patel, TACOM–ARDEC, (973) 724–3828, DSN 880–3828.

ARL–MTO–00–03 Optics Manufacturing Technology (FY00–02). This effort will develop manufacturing technology to enable the affordable fabrication, testing, and assembly of complex optical elements in extremely hard, brittle materials to shapes that conform to the platform on which they will be used. This program will apply magnetorheological finishing (MRF) to conformal optics. MRF is a technique that uses a magnetic field to control the stiffness of a magnetic polishing fluid. Under computer control, the fluid is used for extremely accurate control of polishing to remove subsurface damage and smooth the surface to optical tolerances.

The computer-controlled conventional lens fabrication technology previously developed by the Center of Optics Manufacturing will be extended to fabrication of conformal optical surfaces and off-axis aspheric mirrors. The primary manufacturing processes involved are deterministic microgrinding (DMG) and MRF. DMG shapes optical glass and infrared transmitting materials to submicron tolerances and near-optical surface quality. DMG machinery has been successfully

developed and commercialized for the production of conventional lenses and is presently used by 16 manufacturers for the fabrication of optics for Apache, Javelin, M1A2, and other systems. DMG technology is being extended under a DARPA program to create multiple-axis machine tools to microgrind net shape conformal and off-axis aspheric surfaces in optical glass and IR materials. Cost avoidance is estimated to be $205 million. *Project Manager:* Walter Roy, AMSRL–WM–MD, (410) 306–0803, DSN 458–0802.

ARL–MTO–00–05 Uniform Cannon Tube Reshaping (FY00–03). This MTO will develop, implement, and prove manufacturing and inspection equipment and techniques capable of producing new cannon and reshaping fielded cannon to the defined optimum bore straightness profile. Small, incremental differences in straightness throughout 120-mm cannon tubes will be greatly reduced, and, consequently, the first-round hit probability will be increased. Cannon tube reshaping will be applicable to any precision fire weapon (excluding indirect fire such as artillery or rapid fire weapons such as chain guns). This will include the new M256E1 (longer 120-mm), 155-mm, or any of the smaller caliber tank cannon that may appear on a direct-fire future combat system.

The baseline performance must be established for a control group of 120-mm tubes, and reshaping technologies and techniques must be proved. Dispersion testing will be performed on a controlled lot of cannon to determine hit probability in "as produced" tubes. Other tubes will be reshaped with prototypical tools and algorithms, and a sample of these reshaped tubes will be subjected to fatigue testing to ensure that reshaping does not have an adverse effect on tube life.

During FY01–03, precision reshaping algorithms will be developed for automated or semi-automated shaping of cannon tubes. Precision straightness inspection equipment, capable of inspecting to the tighter tolerances, and automated shaping manufacturing equipment will be developed and integrated with the precision reshaping algorithms. Manufacturing processes will be developed and tubes, manufactured to the new straightness criteria, will be subjected to dispersion testing to demonstrate hit performance improvement. Furthermore, testing will establish that the centerline changes, once made, are permanent (for the life of the tube). Portable inspection and reshaping equipment capable of reshaping fielded tubes during depot maintenance will be developed and deployed. Cost avoidance is estimated to be $260 million. *Project Manager:* Mark Bundy, ARL–WM–BC, (410) 272–3826, DSN 298–6126.

AM–MD–00–05 Advanced Thin-Wall Casting Manufacturing Processes (FY00–01). The objective of this MD is to reduce the manufacturing cost of fabricating multiple-process, complex engine components by developing and demonstrating an advanced thin-wall casting manufacturing capability. This will meet the goal of component cost reduction by >30 percent without weight or quality penalty. Initial applications of this enabling manufacturing technology are to helicopter engines and auxiliary power units (APUs).

A new thin wall manufacturing technology is proposed for this demonstration and development program. The wall thickness achievable is 0.030 inch, compared to >0.100 inch for conventional investment casting. The process involves an investment casting process that provides dimensional and metallurgical integrity for thin-wall components. This process would enable the manufacturing of net-shape, near-net-shape complex, or thin-wall structural castings. Benefits are 30–60 percent component cost reduction by converting from fabrication and assembly to thin-wall casting; rough order of magnitude of the cost avoidance of >$11 million and the ratio of present value benefits to present value investment of >10.9; and broad impact on various Army applications. *Project Manager:* Joe Pratcher, AMCOM, (256) 842–2520, DSN 788–2520.

HQAMC–CD–00–01 Natural Gas, Engine-Drive Air Compressors (NGEDAC) (FY00–01). In an effort to reduce its overall environmental impact and energy consumption, the Army plans to apply NGEDAC technology in support of compressed air systems in fixed facilities. The objectives are to assess the viability of applying NGEDAC technology at six installations, identified by AMC, and provide a full technology demonstration at two installations. The six installations are Charleston Combat Equipment Group–Afloat, Corpus Christi Army Depot, Lone Star Army Ammunition Plant, Pine Bluff Arsenal, Picatinny Arsenal, and Sierra Army Depot. Favorable economy is the prime selection criterion for technology demonstration. The demonstration will evaluate operation and maintenance, compressed air quality, efficiency, reliability, and air emissions. *Project Manager:* Martin Savoie, CEERD–CF–E, (217) 373–6762, (800) 872–2375.

ARL–CD–01–01 Continuous Manufacturing Technology (FY01). This effort will demonstrate a continuous manufacturing process to produce low-cost, low-weight aluminum (Al) metal matrix composite (MMC) components with tailorable properties. The Al MMC will use a continuous fiber reinforced tape. Processing will follow closely the methods associated with those of preform fabrication associated with polymer composites. This program will enable the production of prototype samples and components for various Army and other DoD weapon systems.

The technology developed will enable the use of continuous-fiber-reinforced Al MMC tape to produce precursors and prototypes for items such as thin-wall munition shells, lightweight mortars, sabots, etc. The continuous-fiber-reinforced Al MMC has demonstrated a significant increase in strength over conventional MMC processing, which will enable reductions in weight over traditional components. A multiaxis manufacturing capability will enable the fabrication of more complex geometries. *Project Manager:* Walter Roy, AMSRL–WM–MD, (410) 306–0803, DSN 458–0802.

COMPOSITES PROCESSING AND MANUFACTURING

Goals

Efforts will be directed to developing and implementing processes and capabilities that reduce the costs associated with acquiring weapon systems with composite parts. Composites have been identified as a high priority under the new 2000 *Defense Science and Technology Strategy* and are considered to be critical to the development of advanced land combat vehicles. One of the major efforts that Army ManTech is focusing on is Knowledge and Process Tools for Manufacturing of Affordable Composites (ARL–MTO–99–01).

Major Technical Challenges

Advanced composites design, tooling, materials, processes, fabrication, assembly, and quality must be further developed to reduce the weight of weapon systems, extend their range, reduce their logistics trail, and enhance technological capabilities to meet Objective Force requirements.

ARL–MTO–99–01 Knowledge and Process Tools for Manufacturing of Affordable Composites (FY00–03). This MTO is aimed at developing and demonstrating by FY03 advanced structural composite material processes and tools that significantly reduce the time and cost to manufacture large-scale composite components for rotary-wing vehicles, ground vehicles, and munitions. Such processes will include robotic tow and tape (thermoplastic and thermoset) place-

ment; resin transfer molding and resin infusion molding; electron beam and x-ray curing; preform stitching, weaving, and braiding; and out-of-autoclave curing. These processes will be combined with sensor-based process feedback control and resin flow simulation.

This MTO addresses the need for scaling up promising emerging composite manufacturing technologies for deployment in design, analysis, and actual shop floor practices. It will optimize recent developments in processing, process modeling, analysis, and cost-estimating technologies to production weapon systems. Processing and manufacturing contribute 50 to 60 percent of the total delivered cost of a typical composite part. It has been shown that over 60 percent of the life-cycle cost is already built in by low-rate initial production. Trial-and- error and past-experience practices in product development are typically costly and become even more so with complex systems. One of the most dramatic improvements will involve the extensive use of "intelligent" processing technologies, which include the synthesis of optimal, real-time process decisions based on continuously fused sensor, model, and control algorithm data. Cost avoidance is estimated to be $464 million, not including life-cycle cost avoidances. This MTO addresses key composite user requirements for future combat vehicle and munitions by reducing weight by 15 percent. *Project Manager:* Walter Roy, AMSRL–WM–MD, (410) 306–0803, DSN 458–0802.

SBC–MD–00–07 Seam-Sealing Technology Manufacturing Processes (FY00–01). A new one-step, self-sealing capability to replace the current two-step sealing is required for environmentally protective end items (e.g., tents, tarps, chemical protective uniforms, rain suits). Current technology fails to incorporate self-sealing capabilities, whereby environmentally protective end-items (e.g. tents, tarps, chemical protective uniforms, rainsuits, Extended Cold Weather Clothing System (ECWCS) and equipage) can be simultaneously sewn and sealed over seams. As a result, a high cost is incurred to independently apply a seam-sealing tape to prevent leakage. This process is like sewing the end item a second time, and the process progresses at only half the speed of sewing. Therefore, manual labor represents a large portion of the item's cost. Furthermore, it is impractical for end items such as tents, tarps, and other covers to be separately taped due to their large size. The proposed process will reduce labor costs by 22–30 percent. Given a 22 percent savings, a cost avoidance could be more than $3 million per year just from ECWCS. *Project Manager:* Steve Szczesuil, SBCCOM, (508) 233–4695, DSN 256–4695.

ELECTRONICS PROCESSING AND MANUFACTURING

Goals

This technology effort will develop and deploy affordable, robust manufacturing processes and capabilities for electronics critical to Army applications over their full life cycle. Army ManTech is focusing on the following technology efforts:

- ManTech for Cooled and Uncooled IR Staring Sensors (CE–MTO–98–01)
- Wafer-Applied Seal for PEM Protection (AM–MTO–99–02)
- Low-Cost MEMS Inertial Measurement Units (AM–MTO–00–04)
- Low-Cost Manufacturing Technology for Lightweight Electronic Scanning Antennas (AM–MD–99–01)
- Affordable Digital Signal Processing Systems (AM–MD–00–06)

- Advanced Filter Materials for High-Performance UV Sensors (CE–MD–00–01)
- Active Matrix LCDs (CE–MD–00–02)
- Short-Wavelength IR-Gated Camera Tubes (CE–MD–00–03)
- Active Matrix Electroluminescent Displays (CE–MD–00–04).

Major Technical Challenges

Efforts are needed to focus on (1) the Army's need for smaller, low-cost, high-performance IR imaging systems and IR focal plane arrays (FPAs); (2) near-hermetic coatings to allow use of plastic encapsulated microcircuits for long-term missile and munitions storage where high-cost ceramic hermetic electronic packages have been required; (3) low-cost MEMS IMUs to meet the needs of tactical missiles and guided rockets; (4) advanced filters for UV sensors; (5) active matrix liquid and electroluminescent displays; and (6) affordable digital signal processing systems.

CE–MTO–98–01 Manufacturing Technology for Cooled and Uncooled IR Staring Sensors (FY98–02). Costly uncooled FPA sensors must be replaced with significantly less expensive uncooled versions in as many weapon systems as possible. Significant advances are needed in the manufacturing technology that will make cooled FPAs more affordable for those systems requiring the highest level of sensitivity and resolution. New processes are needed to reduce or eliminate yield limiters, reduce cycle times, improve performance, reduce power consumption, and reduce cost by 10–20 percent. Manufacturing techniques must be refined to enable the development of high-resolution uncooled arrays with smaller pixels. Those efforts should build on available design tools, process control equipment, testing equipment, and FPA/ROIC (readout integrated circuit) fabrication techniques to establish new manufacturing processes for the production of large-string cooled FPAs. The sensors must provide increase sensitivity and improved capability to detect and identify low-observable targets.

This MTO will develop manufacturing technologies for cooled and uncooled IR staring sensors, including process development in uncooled and cooled FPAs and improvements in IR optics manufacturing. It will demonstrate affordable high-performance FPAs for use in planned and emerging weapon systems. Reduced-pixel-size monolithic uncooled staring FPAs will enable increased sensitivity and resolution, smaller and lighter weight systems, and product improvements of cooled FPA applications. Large-area cooled staring FPAs will enable increased sensitivity, improved detection and identification of low-observable targets, and 360-degree panoramic coverage (Figure G–1).

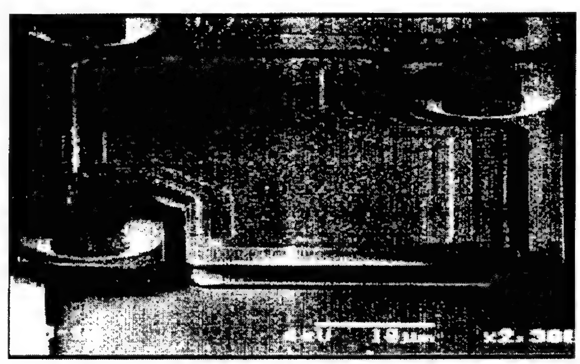

FIGURE G–1. UNCOOLED FPA PIXEL

Initial cost avoidance is estimated to be $434 million. Staring cooled and uncooled FPAs offer significant performance capability for emerging weapon systems. The uncooled FPAs in transition include those for thermal weapon sights, drivers' vision enhancers, OICW, and Land Warrior systems. The cooled FPAs in transition include those for the FCS and Joint Strike Fighter. *Project Manager:* Neil Supola, CECOM–RDEC–NVL, (703) 704–3181, DSN 654–3181.

AM–MTO–99–02 Wafer-Applied Seal for Plastic-Encapsulated Microcircuits (PEM) Protection (FY99–01). New and enhanced coating processes and equipment must be developed that improve the reliability and increase the packaging yields of PEMs in military systems subjected to harsh environments and long-term storage. The required shelf life of Army missiles ranges from 10 to 20 years under a variety of uncontrolled storage conditions. Current PEMs have not been proved to be reliable under long-term unpowered storage in harsh environments, but they continue to be inserted into many weapon systems based on initial cost avoidance and non-availablility of hermetic parts. What is needed to improve commercial PEM reliability is a wafer coating process that protects against moisture and ionic contamination to nearly the same level as hermetic devices.

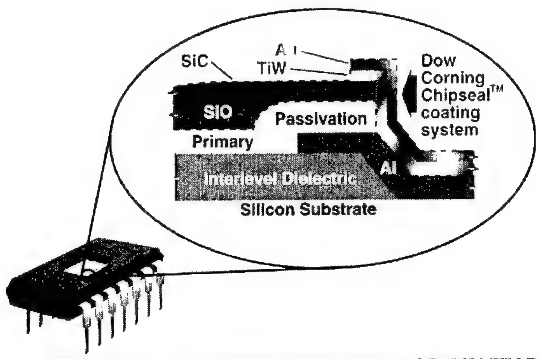

FIGURE G–2. COATING CONCEPT FOR MILITARY PLASTIC-ENCAPSULATED MICROCIRCUITS

This MTO will demonstrate a protective coating by FY02 that provides a 78 percent improvement in resistance to internal PEM corrosion mechanisms while improving integrated circuit (IC) fabrication and packaging yields by 5 percent. The coating will be promoted as industry-standard passivation (Figure G–2). Exit criteria include a 1 to 5 percent IC fabrication and assembly yield increase, a 98 percent survival rate in highly accelerated stress test and temperature cycling testing, and adoption in most commercial and military markets. Transition is planned during FY02–03 for military-grade component suppliers, FY03–04 for industrial-grade IC suppliers, and FY04–05 for commercial-grade IC suppliers. *Project Manager:* Peter Black, AMCOM, (256) 876–3004, DSN 746–3004.

AM–MTO–00–04 Low-Cost Microelectromechanical Systems (MEMS) Inertial Measurement Units (IMUs) (FY00–03). This project will establish and demonstrate flexible manufacturing capabilities for tactical-grade, MEMS-based IMUs that meet the needs of tactical missiles and guided rockets. A cost avoidance of $352 million and a benefit-to-investment ratio of 30 are projected. Other benefits include weight, size, and power reductions that lead to improved performance by allowing for increased range or larger payload and potential savings in logistics.

A common tactical-grade IMU is needed that weighs less than 0.7 pound, has a volume of less than 8 cubic inches, requires less than 1 watt of power, and costs less than $1,000 in production quantities of 10,000 units per year (up to an 87 percent reduction in unit cost). The processes developed under this program will be demonstrated by building prototype IMUs for the Advanced Precision Kill Weapon System (APKWS) and Modernized Hellfire engineering and manufacturing development programs.

The current generation of IMUs, ring-laser gyros, and interferometric fiber-optic gyros are expensive ($4,000 to $15,000), take up a significant volume (25 cubic inches), are relatively heavy (1.5 pounds), and require up to 10 watts of power. Emerging Army tactical missile and guided rocket systems (Modernized Hellfire, APKWS, and others) require tactical-grade IMUs (with drift rates down to 1 deg/hr) and place a premium on subsystem weight, volume, and power requirements as well as affordability. *Project Manager:* Roy Lindberg, AMCOM, (256) 842–7991, DSN 788–7991.

AM–MD–99–01 Low-Cost Manufacturing Technology for Lightweight Electric Scanning Antenna (ESA) (FY99–01). The Army requires a communications system that can maintain continuous, secure contact while units are on the move. In order to maintain security, battlefield units will use a satellite or aerial vehicle as a relay. Such a system has been demonstrated, but at a cost of approximately $400,000, which is too expensive for the Army. These systems will use small ESAs on the order of 18 by 12 by 5 inches. The antennas will be vehicle mounted with a low profile to reduce signature. The ESAs provide a rapid scanning capability that will allow the system to track the relay vehicle while all vehicles are on the move. Tactical radar and communications antennas are critical elements for C^3I on the battlefield. The associated cost has made it impossible for the technology to be implemented. Therefore, it is necessary to invest in manufacturing and testing methodology for affordable, lightweight antennas.

This project will develop low-cost, large-area microwave materials and manufacturing process parameters for high-volume production of ferroelectric materials and components used in ESAs. These materials will provide for smaller, lighter, and less expensive communications and radar antennas to replace current ferrite, phase-shifter technology. *Project Manager:* J. Synowczynski, ARL, (410) 306–0750, DSN 458–0750.

AM–MD–00–06 Affordable Digital Signal Processing (DSP) Systems (FY00–02). Guidance and control (G&C) is the leading cost driver of guided missiles and weapons, and DSP is the key technology in G&C. DSP commercial applications have been increasing in cell phones, communications, and sensors systems. Leveraging of commercial DSP technologies and manufacturing capability can significantly impact new Army G&C capabilities and upgrades while reducing obsolescence issues.

This effort will redesign G&C modules to reduce cycle times and unit production costs. Transitioning commercial technologies in DSP will reduce the average development cycle times and unit production costs by 25 percent of current-generation G&C modules. Near-term cost avoidance is estimated at $71.8 million for the Tactical Missile System (TACMS) alone. However, other significant benefits and cost avoidance will be obtained from reduced cycle times for developing new performance upgrades or by eliminating obsolete DSP components and technologies. *Project Manager:* Daron Holderfield, AMCOM, (256) 876–1754, DSN 746–1754.

CE–MD–00–01 Advanced Filter Materials for High-Performance UV Sensors (FY00–01). The Advanced Threat Infrared Countermeasures/Common Missile Warning System (ATIRCM/CMWS) is a tri-service program using state-of-the-art technology to develop a missile warning system for all DoD aircraft. The AN/AAR–57 missile warning system uses 4 to 6 SU–202/AAR–57 sensors to detect incoming threat missiles. These sensors are designed to work in the ultraviolet portion of the electromagnetic spectrum, and they have very unique spectral bandpass and band-reject characteristics. To achieve the required level of optical performance, the optical elements of the sensors incorporate a filtering characteristic as well as a lens prescription. This is accomplished by constructing these elements from exotic materials known as MGX, LZ–1, and DL–12.

This effort will develop and demonstrate manufacturing processes for increasing producibility and performance of UV sensors. Focus will be placed on defect reduction, yield improvement, and cost savings. The current problem is that the producibility for these three materials is low, with a maximum rate of supply being only 20 filter element sets per month. (Each set consists of three LZ–1 elements, one MGX element, and one DL–12 element.) Future demands for CMWS will require delivery rates as high as 200 filter element sets per month. An effort is required to

develop the processes that will allow these materials to be produced economically. *Project Manager:* Steven Messervy, ATIRCM/CMWS/ASE, (256) 313–4560, DSN 897–4560.

CE–MD–00–02 Active Matrix Liquid Crystal Displays (FY00–01). Active matrix liquid crystal displays (AMLCDs) that are 1280 × 1024 have been baselined by the Comanche Integrated Product Team as the image source for the RAH–66 Comanche Helmet Integrated Display and Sight System (HIDSS). The HIDSS is a mission-critical component for the Comanche helicopter. It generates heads-up images for both the pilot and the copilot, displaying forward-looking infrared or low-light-level TV imagery combined with symbology for the flight, mission, and weapon systems. Thus, pilots will use the HIDSS full time for flying the helicopter under all conditions. The Comanche helicopter will not field without the HIDSS.

Currently, the production yield for the AMLCD is 1.4 percent with a unit cost of approximately $11,800 per display. The program unit design-to-cost is $1,000–$2,500. The major cost factor is the current low yield. Manufacturing technology for the Comanche display is immature, and the accelerated pace of the Comanche program has resulted in the need to rapidly mature the production of the display. The Army requires a low-cost, high-performance, high-resolution, mission-critical AMLCD to meet current Comanche program funding restraints and performance requirements. Producing low-cost AMLCDs will be accomplished by addressing major yield hits (liquid crystal processing, row and column defects, display transmission, and pixel defects), and increasing yield to at least 13 percent while still meeting all of the high-performance specifications of the Comanche HIDSS program. *Project Manager:* Neil Supola, CECOM–RDEC–NVL, (703) 704–3181, DSN 654–3181.

CE–MD–00–03 Short-Wavelength Infrared-Gated Camera Tubes (FY00–02). The short-wavelength infrared (SWIR) camera will be employed in a family of military systems, each of which is devoted to target detection, recognition, and range measurement. The systems will consist of a wide field-of-view, long-wavelength IR (LWIR) sensor for target detection, a gated SWIR camera, and an eye-safe 1.54-μm laser for range measurement and target illumination. Army systems using this technology include Unattended Ground Vehicle, Unmanned Aerial Vehicle, Hand-Held Binocular, Crew-Served Weapon Sight, Future Scout Cavalry Vehicle, Bradley Fight Vehicle (M–2), and Main Battle Tank (M–1).

The SWIR sensor technology is currently being evaluated by the Air Force under the ERASER program for future applications on the Lantern, F–18AT, P–3, F–117, Apache, Kiowa, Cobra, and Predator. This ManTech program will address low yield of SWIR sensors that will result in the reduction of unit costs from $6,054 to $1,427 per copy. A source for SWIR sensors capable of economic production is extremely important to future affordability and fielding of Army and Air Force systems. *Project Manager:* Neil Supola, CECOM–RDEC–NVL, (703) 704–3181, DSN 654–3181.

CE–MD–00–04 Active Matrix Electroluminescent (AMEL) Displays (FY00–02). It is estimated that DoD will procure 6,000–12,000 miniature displays per year during the next decade (nominally 9,000 units per year in specific). Applications include the Army Land Warrior head-mounted displays for virtual reality, and the joint Army–Air Force lightweight laser designator rangefinders, HSTAMIDs, and Aviator's Night Vision Imaging System heads-up displays (HUDs). The quantity will be dependent on the cost of the miniature displays. Based on current costs covering labor, materials, overhead, margin, and yield, the price to DoD for a typical display is estimated at $705 per unit at the expected volume level over this period of time.

New and improved AMEL manufacturing processes will be developed, producing improved yields that will significantly lower the cost. It is estimated that the original 6,000 units per year for the government would grow to 8,000 units units per year. With the improved yield at these volume levels, the price would be about $310 per unit. This price differential of $395 per unit over the 8,000 units used by DoD represents an average cost avoidance of $3.16 million per year, or $31.6 million over the 10-year planning window. *Project Manager:* Neil Supola, CECOM–RDEC–NVL, (703) 704–3181, DSN 654–3181.

TECHNOLOGY OBJECTIVES

The roadmap of technology objectives for ManTech is shown in Table G–1.

TABLE G–1. TECHNICAL OBJECTIVES FOR MANTECH

Technology Subarea	Near Term FY01–02	Mid Term FY03–08	Far Term FY09–16
	ENERGETICS AND MUNITIONS		
Objective Individual Combat Weapon & Objective Crew-Served Weapon	Develop powdered metal manufacturing process to produce OICW tungsten warhead Develop blank, cup & draw manufacturing process for steel OCSW warhead Develop forging process for steel OCSW warhead Adapt OCSW steel warhead process for OICW steel warhead Develop technologies to reduce manufacturing costs for OICW & OCSW munitions (20 mm & 25 mm)	Demonstrate manufacturing technologies to reduce cost of OICW bursting munitions by $7.67 per round & OCSW by $2.52 per round	
Munitions Manufacturing Technology	Develop improved processes for production of tantalum explosively formed penetrator Develop software technology necessary for design, development, & manufacture of composite munition components & systems Establish accelerated munitions manufacturing for the M829E3		
Totally Integrated Munitions Enterprise	Develop general-purpose collaborative tools & open modular architecture controller demonstrations		
	METALS PROCESSING AND MANUFACTURING		
Large-Caliber Life Extension Via Tantalum Sputtering	Demonstrate modeling of sputtering process & coat tubing sections; design/develop tantalum sputtering target	Manufacture & set up 120-mm/155-mm tantalum sputtering process Coat/deliver one 120-mm & 155-mm tantalum-coated cannon barrel, & conduct demonstration of sputtering process	Continue transition of tantalum refractory metal-resistant coating to all DoD large cannon barrels
Optics Manufacturing Technology	Measure accuracy of conformal surfaces to optical precision, & describe nonaxisymmetric surfaces to 10-nm tolerances Demonstrate technology on Comanche, OICW, LRAS3, Stinger, and INOD	Continue development of low-cost optic & conformal optic components	Continue development of low-cost optic & conformal optic components
Center for Optics Manufacturing	Complete MRF & microgrinding studies		
Uniform Cannon Tube Reshaping	Demonstrate bore mapping & dispersion testing of controlled lot of 120-mm M256 cannon tubes Perform fatigue testing of tubes reshaped with prototype technologies, & test prototype precision reshaping algorithms	Demonstrate portable test/reshaping equipment for modifying 120-mm fielded cannon tubes, & prove out the manufacturing process & dispersion testing of tubes manufactured to new centerline profile requirements; improve first-round hit probability	Continue development of improvements to cannon tube profiling

TABLE G–1. TECHNICAL OBJECTIVES FOR MANTECH (CONT'D)

Technology Subarea	Near Term FY01–02	Mid Term FY03–08	Far Term FY09–16
METALS PROCESSING AND MANUFACTURING (CONT'D)			
Manufacturing Demonstrations	Develop thin-wall casting technology (0.03 in vs. >0.1 in) for helicopter auxiliary power units & propulsion engines Develop natural gas, engine-driven compressor technology	Integrate into Comanche engine/cost reduction initiatives or Longbow & Apache APUs	Continue improvement & transition of thin-wall casting technology
Continuous Manufacturing Technology	Reduce the touch labor and overall cost of manufacturing high-performance MMC materials Develop and demonstrate a continuous, multiaxis MMC manufacturing system capable of producing complex components with tailorable properties		
COMPOSITES PROCESSING AND MANUFACTURING			
Knowledge & Process Tools for Manufacturing of Affordable Composites	Demonstrate models for optimal fabrication, closed-loop cure process control, & resin flow simulation accuracy Demonstrate adaptive out-of-autoclave tooling to optimize cure cycles of structures of highly variable thickness, & advance embedded sensor technology Demonstrate user-friendly model & sensor control for shop floor use, & demonstrate 4- to 6-sigma process control for advanced processes Develop manufacturing processes for seam-sealing technology	Demonstrate manufacturing simulation & embedded sensors to reduce process development cycle by 40% Reduce thick-composite fabrication cost for armored vehicles by 30% & labor by 50% using integrated process development Develop real-time processing tool to provide flow modeling database for highly reinforced composite materials Continue development of advanced soldier support technologies	Continue transition of advanced structural composite material processes/tools for Army systems Continue development of advanced soldier support technologies
ELECTRONICS PROCESSING AND MANUFACTURING			
Manufacturing Technology for IR Cooled & Uncooled Staring Sensors	Demonstrate greater than 50% yield for 288 × 384 uncooled monolithic FPA with at least 4X reduced pixel size & improved vacuum packaging Initiate manufacturing process improvement in FPA/ROIC integration controls, testing, & ROIC yields of cooled FPAs	Demonstrate 15% yields & a 2X cost reduction for 480 × 640 cooled FPAs/Dewars Transfer improved production processes from 480 × 640 to 480/960 × 1280 cooled FPAs/Dewars Demonstrate 25% yields & 3X cost reduction for 480/960 × 1280 cooled FPAs/ Dewars	Continue transition of next-generation manufacturing processes for monolithic, multifunction, multispectral advanced FPA cooled & uncooled sensor systems
Wafer-Applied Seal for PEM Protection	Establish material system and investigate, select, & develop application process for selected material Initiate component military qualification & beta testing in industry IC fabrication facilities	Develop enhanced coating processes & equipment that improve reliability & increase packaging yields of PEMs Demonstrate coating process for the chip sealing material at < $200 per wafer Demonstrate the chip sealing process on at least one industry semiconductor chip fabrication line with data validating the predetermined exit requirements	Continue transition of PEM IC coating technology to Army systems (e.g., Javelin, BAT, Longbow, Patriot, Comanche) & to Navy/Air Force missiles
Low-Cost MEMS IMUs	Develop processes to help automated manufacturing concepts & optimum level of electronic integration Initiate development of automated equipment/control software	Complete the fabrication of IMU prototypes, conduct MEMS IMU demonstration, & provide IMUs to participating PMs for system test and validation	Continue transition of low-cost MEMS to Army systems
Manufacturing Demonstrations	Redesign G&C modules using commercial DSPs & electronics Demonstrate 20X less power requirements, 50X less volume, and 83% reduction in phase shifter cost Increase yield & throughput, & decrease process time UV countermeasures & missile warning Demonstrate low-cost, high-performance display for Comanche helmet Improve cost & yield of SWIR camera tube Improve cost & yield of AMEL displays	Insert form, fit, & function of commercial DSP G&C modules & conduct HWIL tests Continue transition into Army EHF applications Demonstrate 90% yield, 30-day process time, & 80 sets/mo throughput Improve yield & manufacturing rate, & lower cost of Army EDSs Improve yield & manufacturing rate, & lower cost of EDSs	Continue transition into Army DSP & EHF applications Improve yield, manufacturing rate, & lower cost of Army EDSs

GLOSSARY OF ABBREVIATIONS AND ACRONYMS AND INDEX

Glossary

Abbreviations and Acronyms

Symbols/Numbers

μA	microampere
μm	micrometer
2D	two-dimensional
3D	three-dimensional
4D	four-dimensional

A

A	ampere
A^2CS	antennas across the communications spectrum
AAAV	Advanced Amphibious Assault Vehicle
AAR	after action review
AATD	Aviation Applied Technology Directorate
ABB	Asea Brown–Boveri
ABCS	Army Battle Command System
ABN	airborne
ACN	airborne communications node
ACR	advanced concepts and requirements
ACS	Aviation Center and School
ACT	active control technology
ACTD	Advanced Concept Technology Demonstration
ADKEM	Advanced Kinetic-Energy Missile
ADL	advanced distributed learning
ADS	advanced distributed simulation; Area Denial System
AEC	airborne electronic combat
AES	aviation electronic systems
AFDD	Aeroflightdynamics Directorate
AFSS	Advanced Fire Support System
AGCRC	The Australian Geodynamics Cooperative Research Center (Australia)
AGMIID	Advanced Geospatial Management for Information Integration and Dissemination
AHPC	Athens High-Performance Computing Laboratory (Greece)
AHRS	Attitude and Heading Reference System
AI	artificial intelligence
AIDS	acquired immune deficiency syndrome
AIN	Army Interoperability Network
Al	aluminum
ALERT	Air/Land Enhanced Reconnaissance and Targeting
ALSE	aviation life support equipment
ALYCAT	Aeromechanics Lynx Control and Agility Research Testbed
AMBL	Air Maneuver Battle Laboratory
AMC	Army Materiel Command
AMCOM	Aviation and Missile Command
AMD	air and missile defense
AMDS	advanced mine detection sensor
AMEDD	Army Medical Department
	active matrix electroluminescent
AMLCD	active matrix liquid crystal display
AMP	*Army Modernization Plan*
AMRDEC	Aviation–Missile Research, Development, and Engineering Center
AMS GOSC	Army Modeling and Simulation General Officer Steering Committee
AMSEC	Army Modeling and Simulation Executive Committee
AMS–H	Advanced Missile System—Heavy
AMSO	Army Model and Simulation Office
AMUST–D	Airborne Manned/Unmanned System Technology Demonstration
ANN	artificial neural network
ANSI	American National Standards Institute
ANVG	Advanced Night Vision Goggle
ANVIS	Aviator's Night Vision Imaging System
AOA	analysis of alternatives
AOAP	Army Oil Analysis Program
APG	Aberdeen Proving Ground
API	application program interface
APKWS	Advanced Precision Kill Weapon System
APLA	antipersonnel land mine alternative
APS	Active Protection System; alternative propulsion sources
APU	auxiliary power unit
ARCAT	Advanced Rotorcraft Aeromechanics Technologies
ARDEC	Armament Research, Development, and Engineering Center
ARI	Army Research Institute for the Behavioral and Social Sciences
ARL	Army Research Laboratory
ARM	aviation rockets and missiles
ARO	Army Research Office
ARS	angular rate sensor
ART II	Advanced Rotorcraft Transmission Phase II
ASCC	Army Service Component Command
ASET	Association of Super-Advanced Electronic Technologies
ASHPC	Advanced Simulation and High-Performance Computing
ASIC	application-specific integrated circuit
ASMO U.K.	Association for Structural and Multidisciplinary Optimization in the United Kingdom
ASTMP	*Army Science and Technology Master Plan*
ASTWG	Army Science and Technology Working Group

ATACMS	Army Tactical Missile System
ATCCS	Army Tactical Command and Control System
ATD	Advanced Technology Demonstration
ATGM	antitank guided missile
ATGW	antitank guided weapon
ATIRCM	Advanced Threat Infrared Countermeasures
ATLAS	Advanced Technology Lightweight Artillery System
ATM	asynchronous transfer mode
ATR	automatic target recognition
Au	gold
AUTONAV	Next-Generation Autonomous Navigation System (Germany/U.S.)
AVRDEC	Aviation Research, Development, and Engineering Center
AWE	Army Warfighting Experiment

B

BAS	Battlefield Automated System
BAT	Brilliant Antitank
BBP	blood-borne pathogens
BC	battle command
BC^2	battlespace command and control
BCBL	Battle Command Battle Laboratory
BCIS	Battlefield Combat Identification System
BCNS	behavioral, cognitive, and neural sciences
BCV	Battle Command Vehicle
BDA	battle damage assessment
BFA	battlefield functional area
BFV	Bradley Fighting Vehicle
BIAM	Beijing Institute of Aeronautical Sciences (China)
BiCMOS	bipolar complementary metal-oxide semiconductor
BIT	built-in test
BITS	Battlefield Information Transmission System
BLOS	beyond line of sight
BLWE	battle laboratory warfare experiment
BMD	ballistic missile defense
BMDO	Ballistic Missile Defense Organization
BMFT	Bundesministerim fur Forschung und Technologie
Bn	battalion
BOA	battlefield ordnance awareness
BRAC	Base Realignment and Closure [Commission]
BRIMS	Basic Research Institute in the Mathematical Sciences (United Kingdom)
BRITE–EURAM	Basic Research for Industrial Technologies in Europe—European Advanced Materials
BSFV–E	Bradley Stinger Fighting Vehicle—Enhanced
BTN	battlespace tactical navigation
BV	battlefield visualization
BVI	blade–vortex interaction
BW	biological warfare

C

C	centigrade
C^2	command and control
C^2TL	Commercial Communications Technology Laboratory
C^2V	command and control vehicle
C^3	command, control, and communications
C^3I	command, control, communications, and intelligence
C^3S	command, control, communications, and survivability
C^4	command, control, communications, and computers
C^4I	command, control, communications, computers, and intelligence
CABS	Cockpit Airbag System
CAC^2	combined arms command and control
CAD	computer-aided design
CAE	computer-aided engineering
CAGES	Common Air/Ground Electronic Combat Suite
CAM	computer-aided manufacturing
CAPS	Counteractive Protection System
CASE	computer-aided software engineering
CAT	Crew Integration and Automation Testbed
CATT	combined arms tactical trainer
CAV	composite armored vehicle
CAVE	computer-aided virtual environment
CB	chemical and biological
CBD	chemical and biological defense
C–C	carbon–carbon
CCAWS	Close Combat Antiarmor Weapon System
CCS	close combat support
CD	congressionally directed
CDA	commander's decision aid
CDMA	code division multiple access
CE	chemical energy
CEB	Cazuax, the Centre D'Etudes du Bouchet (France)
CECOM	Communications–Electronics Command
CEO	Center for Electro-Optics (Korea)
CEP	Concept Experimentation Program; circular error probable
CERDEC	Communications–Electronics Research, Development, and Engineering Center
CERL	Construction Engineering Research Laboratory
CFD	computational fluid dynamics
CGA	computer-generated actors
CGF	computer-generated forces
CGS	common ground station
CHL	Coastal Hydraulics Laboratory
CHPS	Combat Hybrid Power System
CICM	communications integration and cosite mitigation
CID	combat identification
CIDDS	Combat Identification for Dismounted Soldier
CINC	commander in chief

CISD	Computational and Information Science Directorate
CKEM	Compact Kinetic-Energy Missile
CLAWS	Container Launched Attack Weapon System
CLU	container launch unit
cm	centimeter
CM	countermeasures; Common Missile
CMC	ceramic matrix composite
CMDA	code division multiple access
CME	common modeling environment
CMWS	Common Missile Warning System
CNRS	Centre Nationale de la Recherche Scientifique (France)
COA	course of action
COAA	course-of-action analysis
COMINT	communications intelligence
CONOPS	continuous operations
CONUS	continental United States
COTS	commercial off the shelf
CP	command post
CRREL	Cold Regions Research and Engineering Laboratory
CS	combat support
CS/TMBS	Crew Station/Turret Motion Base Simulator
CSIR	Chemistry, Software, and Information Resources [formerly known as the Council for Industrial Research (South Africa)]
CSRDF	Crew Station Research and Development Facility
CSS	combat service support
CSSBL	Combat Service Support Battle Laboratory
CSSCS	Combat Service Support Control System
CTC	Combat Training Center
CTIS	Combat Terrain Information System
CTV	control test vehicle
CVD	chemical vapor deposition
CW	chemical warfare

D

D&SABL	Depth and Simultaneous Attack Battle Laboratory
DAMA	demand assignment multiple access
DARO	Defense Airborne Reconnaissance Office
DARPA	Defense Advanced Research Projects Agency
DASA	Daimler–Chrysler Aerospace (Germany)
dB	decibel
DBBL	Dismounted Battlespace Battle Laboratory
DBC	digital battlefield communications
DBS	dismounted battlespace
DCD	Director of Combat Development
DE	directed energy
DECHEMA	Deutsche Gesellschaft für Chemisches Apparatewesen, Chemische Technik und Biotechnologie e.V. (Germany)
deg/hr	degrees per hour
DEM	digital elevation model
DEPSECDEF	Deputy Secretary of Defense
DERA	Defense Evaluation and Research Agency (United Kingdom)
DEW	directed-energy weapon
DFL	direct-fire lethality
DIL	Digital Integration Laboratory
DIS	distributed interactive simulation
DISN	distributed interactive simulation network
DKFZ	Deutsches Krebsforschungszentrum (Germany)
DLA	Defense Logistics Agency
DLR	Deutsche Zentrum für Luft- und Raufahrt e.V. (Germany)
DMBL	Dismounted Battle Laboratory
DMG	deterministic microgrinding
DMSO	Defense Modeling and Simulation Office
DNA	deoxyribonucleic acid
DNBI	diseases and nonbattle injuries
DOCC	Deep Operations Coordination Center
DOE	Department of Energy
DOF	degrees of freedom
DPICM	dual-purpose improved conventional munition
DRAMA	Dynamic Readdressing and Management for Army 2010
DRE	Defense Research Establishment (Canada)
DREO	Defense Research Establishment—Ottawa
DRES	Defense Research Establishment—Suffield
DREV	Defense Research Establishment—Valcartier
DSA	depth and simultaneous attack
DSB	Defense Science Board
DSCS	Defense Satellite Communications System
DSO	Defense Science Organization
DSP	digital signal processing
DSPW	Digital Stereo Photogrammetric Workstation
DSTO	Defense Science and Technology Organization (Australia)
DTAP	*Defense Technology Area Plan*
DTD	digital topographic data
DTED	digital terrain elevation data
DTO	Defense Technology Objective
DTOP	digital topographic data
DTRA	Defense Threat Reduction Agency
DTSS	Digital Topographic Support System
DVE	Driver's Vision Enhancer

E

EARC	Electric Armaments Research Center
EC	European Community
ECBC	Edgewood Biological Chemical Center
ECCAI	European Coordinating Committee for Artificial Intelligence
ECCM	electronic counter-countermeasures
ECM	electronic countermeasures
ECRC	European Computer Industry Research Center
ECU	European currency units
ECV Net	European Computer Vision Network
ECWCS	Extended Cold Weather Clothing System
EDOCC	Enhanced Deep Operations Coordination Center

EDS	electronic display system
EELS	early entry, lethality, and survivability
EELSBL	Early Entry, Lethality, and Survivability Battle Laboratory
EFOGM	Enhanced Fiber-Optic Guided Missile
EFP	explosively formed penetrator
EHF	extremely high frequency
EL	Environmental Laboratory
ELINT	electronic intelligence
ELSNET	European Network in Language and Speech
EM	electromagnetic
EMD	engineering and manufacturing development (now SDD)
EMHD	electromagnetic hydrodynamics
EMI	electromagnetic interference
EO	electro-optic(al)
EOCM	electro-optic countermeasures
EPA	Environmental Protection Agency
ERA	explosive reactive armor
ERCIM	European Research Consortium for Informatics and Mathematics
ERDC	Engineer Research and Development Center
ERDEC	Edgewood Research, Development, and Engineering Center
ESA	electronically scanned antenna
ESM	electronic support measure
ESPRIT	European Strategic Program for Research in Information Technology
ESSI	European Software and Systems Initiative
ETC	electrothermal-chemical
EU	European Union
EUREKA	European Research Coordination Agency
EW	electronic warfare

F

F	Fahrenheit
F&L	fuel and lubricants
FADEC	full authority digital engine control
FAMSIM	family of simulations
FAS	Field Artillery School
FATDS	Field Artillery Tactical Data System
$FBCB^2$	Force XXI Century Battle Command Brigade and Below
FCS	Future Combat Systems
FDA	Food and Drug Administration
FDR	future digital radio
FedLab	Federated Laboratory
FEM	Finite Element Model
FEPS	Federation of European Psychophysiological Societies
FETAX	Frog Embryo Toxicity Assay, Eenopus
FFD	foundation feature data
fL	foot-Lamberts
FLIR	forward-looking infrared
FLOT	forward line of own troops
FMTI	Future Missile Technology Integration
FOC	future operational capability
FOTT	follow-on to TOW
FOV	field of view
FPA	focal plane array
FPES	Force Projection Enabling System
FSAP	full-spectrum active protection
FSCS	Future Scout and Cavalry System
FSEE	Fire Support Software Engineering
FSU	former Soviet Union
FSV	Future Scout Vehicle
FTR	future transport rotorcraft
FTRS	Future Transport Rotorcraft System
FXXI LW	Force XXI Land Warrior
FY	fiscal year
FYDP	Future Years Defense Plan

G

g	gravitational force; gram
G&C	guidance and control
GaAs	gallium arsenide
GBB	Groningen Biomolecular Sciences and Biotechnology Institute (Netherlands)
GBF	Gesellschaft Biotechnologische Forschung (Germany)
GCC	ground component command
GCCS	Global Command and Control System
GCSS–A	Global Combat Service Support—Army
GEO	geosynchronous Earth orbit
GHz	gigahertz
GIS	geographic information system
GloMo	global mobile
GLOREAM	Global and Regional Atmospheric Modeling
GMD	German National Research Center for Information Technology
GMP	Good Manufacturing Practices
GND	ground
GOCO	government-owned, contractor-operated
GOTS	government-off-the-shelf
GPS	Global Positioning System
GSL	Geotechnical and Structures Laboratory
GSS	Group Support System
GSTAMIDS	Ground Standoff Mine Detection System
GTV	guided test vehicle

H

HACT	Helicopter Active Control Technology
HCI	human–computer interface
HEAT	high-explosive antitank
HF	high frequency
HgCdTe	mercury–cadmium–telluride
HHA	health hazards assessment
HIDSS	Helmet Integrated Display and Sight System
HIFU	high-intensity focused ultrasound
HIRLAM	High-Resolution Limited Area Model
HITL	hardware in the loop
HLA	high-level architecture

HMD	head-mounted display; helmet-mounted display
HMMWV	high-mobility, multipurpose wheeled vehicle
HMX	cyclotetramethylenetetranitramine
hp	horsepower
HPC	high-performance computing
HPM	high-power microwave
HQDA	Headquarters, Department of the Army
HRED	Human Research and Engineering Directorate
HSD	head-supported device
HSI	human–system interface
HSM	head-supported mass
HTI	horizontal technology integration
HTK	hit-to-kill
HTS	high-temperature superconductivity
HUD	heads-up display
HV	high value; hypervelocity
HVAC	heating, ventilation, and air conditioning
HVOF	high-velocity oxygen fuel
HW	hardware
HWIL	hardware-in-the-loop

I

I/O	input/output
I^2R	imaging infrared
IACS	International Armaments Cooperative Strategy
IAM	Institute for Advanced Materials (Netherlands, Italy)
IAR	Institute for Aerospace Research (Canada)
IAS	Integrated Acoustic System
IBACS	Integrated Battlefield Area Communications System
IC	integrated circuit
ICH	improved cargo helicopter
ICM	integrated countermeasures
ICT	integrated concept team; Institute for Creative Technologies
ID	identification
IDT	information distribution technology
IEC	Integration and Evaluation Center
IEW	intelligence and electronic warfare
IEWCS	intelligence and electronic warfare common sensor
IEWS	intelligence, electronic warfare, and sensors
IFSAR	interferometric synthetic aperture radar
IHADSS	Integrated Helment and Display Site System
IHPTET	Integrated High-Performance Turbine Engine Technology
ILDP	Improved Landmine Detection Project (Canada)
ILP	integrated launch package
IM	insensitive munition
IMETS	Integrated Meteorological System
IMF	intelligent minefield
IMU	inertial measurement unit
IND	investigational new drug
INOD	Improved Night/Day Fire Control/Observation Device
InP	indium phosphide
INRIA	Institut National de Recherche en Informatique et en Automatique (France)
INS	Inertial Navigation System
INVEST	Intervehicle Embedded Simulation Technology
IP	internet protocol
IPB	intelligence preparation of the battlefield
IPOC	international point of contact
IPT	integrated product team
IR	infrared; installation restoration
IR&D	independent research and development
IRBM	intermediate-range ballistic missile
IRCM	infrared countermeasures
IREMBASS	Improved Remotely Monitored Battlefield Sensor System
IRFCM	integrated radio frequency countermeasure
IRT	inertial reticle technology
ISACM	integrated situational awareness countermeasures
ISAT	integration situation awareness and targeting
ISB	intermediate staging base
ISIS	Intelligent Sensing for Innovative Structures (Canada)
ISL	French–German Research Institute
ISO	International Standardization Organization
ISR	intelligence, surveillance, and reconnaissance
ISR&EW	intelligence, surveillance, reconnaissance, and electronic warfare
ISTD	Information Science and Technology Directorate
ISTP	International Solar–Terrestrial Physics program
ITDB	interim theater database
ITL	Information Technology Laboratory
IUSS	Integration Unit Simulation System
IVES	Intravehicular Electronics Suite
IWEDA	integrated weather effects decision aids

J

J/S	jamming-to-signal ratio
JCPMS	JTF Communications Planning and Management System
JCSE	joint continuous strike environment
JDMTP	Joint Defense Manufacturing Technology Panel
JFLCC	Joint Force Land Component Commander
JISR	joint intelligence, surveillance, and reconnaissance
JLOTS	joint logistics-over-the-shore
JPO	Joint Program Office
JPS	joint precision strike
JPSD	Joint Precision Strike Demonstration
JROC	Joint Requirements Oversight Council
JSIMS	Joint Simulation System
JSSAMP	*Joint Service Small Arms Master Plan*
JTA	joint technical architecture
JTAGG	Joint Turbine Advanced Gas Generator
JTF	joint task force
JTRS	Joint Tactical Radio System

JWID	Joint Warrior Interoperability Demonstration
JWSTP	*Joint Warfighting Science and Technology Plan*

K

K	degree Kelvin
KE	kinetic energy
KEAPS	Kinetic-Energy Active Protection System
KEM	kinetic-energy missile
kg	kilogram
kHz	kilohertz
km	kilometer
km^2	square kilometer
KMR	Kwajalein Missile Range
kW	kilowatt

L

L/V	lethality and vulnerability
LADAR	laser radar
LAIRD	Location and Inspection With Range Data
LAM–A	Loitering Attack Munition–Aviation
LAMD	Lightweight Airborne Multispectral Minefield Detection
LAN	local area network
LASERCOM	laser communications
LCAR	low-cost active rotor
LCC	life-cycle cost
LCD	liquid crystal display
LCPK	low-cost precision kill
LCSEC	Life-Cycle Software Engineering Center
LEO	low Earth orbit
LES	Launch and Orientation Module
LETI	Laboratoire d'Electronique, de Technologie, et d'Instrumentation (France)
LIDAR	light detection and ranging
LIMMS	Laboratory for Integrated Micro–Mechanical Systems (France/Japan)
LLDR	lightweight laser designator
LO	low observable
LOAL	lock-on after launch
LOC	lines of communication
LOCAAS	Low-Cost Autonomous Attack Submunition
LOE	limited objective experiment
Log C^2	logistics command and control
LOS	line of sight
LOSAT	line-of-sight antitank
LOTS	logistics-over-the-shore
LOVA	low-vulnerability ammunition
LPD	low probability of detection
LPI	low probability of intercept
$LRAS^3$	Long-Range Advanced Scout Surveillance System
LRIP	low-rate initial production
LS	Lucky Sentinel
LSI	large-scale integration
LW	Land Warrior
LWIR	long-wavelength infrared

M

m	meter; milli
M&P	materials and processes
M&S	modeling and simulation
MANPRINT	manpower and personnel integration
ManTech	manufacturing technology
MASINT	measurement and signature intelligence
MAV	manned aerial vehicle
MBARS	MEMS-Based Angular Rate Sensors
MBB	Messerschmitt–Boelkow–Blohm (Germany)
MBE	molecular beam epitaxy
MBL	Mobility Battle Laboratory
MBMMR	multiband, multimode radio
MBps	megabytes per second
MBS	mounted battlespace
MBSBL	Mounted Battlespace Battle Laboratory
MBT	main battle tank
MCBD	medical chemical and biological defense
MCS	Maneuver Control System
MCSSL	Mobile Crew Station Simulation Laboratory
MCT	MOS-controlled thyristor
MD	Manufacturing Demonstration; missile defense
MEDEA	Microelectronic Development for European Applications
MEIRS	Multiple Electro-Optic/Infrared Sensors
MEMS	microelectromechanical systems
MEO	medium Earth orbit
MEP	mission equipment package
MFS^3	Multifunction Staring Sensor Suite
mg	milligram
MH/K	mine hunter/killer
MHF	modernized Hellfire
MHz	megahertz
MIB	Management Information Base
MICOM	U.S. Army Missile Command
MILSATCOM	military satellite communications
MITI	Ministry of International Trade and Industry (Japan)
MITL	man-in-the-loop
MJ	megajoule
MK/K	mine hunter/killer
MLRS	Multiple Launch Rocket System
MLS	multilevel security
mm	millimeter
MMBL	Mounted Maneuver Battle Laboratory
MMC	metal matrix composite
MMR	multimission radar
MMW	millimeter wave
MMWS	Multimission Weapon System
MNS	mission needs statement
MOA	memorandum of agreement
ModSAF	Modular Semiautomated Forces
ModStealth	Modular Stealth
MOE	measure of effectiveness
MOP	measure of performance

MOPP	mission-oriented protective posture
MOS	metal oxide semiconductor
MOSAIC	Multifunctional On-the-Move Secure, Adaptive, Integrated Communications
MOUT	military operations in urbanized terrain
MP-ERM	Multipurpose Extended-Range Munition
mph	miles per hour
MPP	massively parallel processing
mps	miles per second
MPT	manpower, personnel, and training
MRC	Medical Research Council (United Kingdom); military relevant chemical
MRDEC	Missile Command Research, Development, and Engineering Center
MRF	magnetorheological finishing; Materials Research Facility
MRI	magnetic resonance imaging
MRSP	Medical Readiness Strategic Plan
ms	millisecond
MSBL	Maneuver Support Battle Laboratory
MSCM	multispectral countermeasures
MSE	mobile subscriber equipment
MSTAR	MLRS Smart Tactical Rocket
MTBF	mean time between failure
MTBR	mean time between replacement
MTDBL	Mounted Battle Laboratory
MTI	moving target indicator
MTO	Manufacturing Technology Objective
MVU	machine vision unit
MWIR	mid-wavelength infrared

N

nA	nanoampere
NAC	National Automotive Center
NAL	National Aerospace Laboratory
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
Nb3Sn	niobium tin
NBC	nuclear, biological, and chemical
NCIC	National Research Center for Intelligent Computing System (China)
NCO	noncommissioned officer
NDE	nondestructive evaluation
NDI	nondevelopmental item
NGEDAC	natural gas, engine-drive air compressor
Ni	nickel
NIJ	U.S. National Institute of Justice
NIMIC	NATO Insensitive Munitions Information Center
N–ISDN	Narrowband—Integrated Services Digital Network
NLOS	non-line-of-sight
NLP	natural language programming
nm	nanometer
NMRI	Naval Medical Research Institute
NQR	nuclear quadrupole resonance
NRDEC	Natick Research, Development, and Engineering Center
NRIM	National Research Institute for Metals (Switzerland, Japan)
NSC	Natick Soldier Center
NTAPS	Near-Term Active Protection System
NTC	National Training Center
NTO	nitrogen tetroxide
NVESD	Night Vision and Electronic Sensors Directorate
NV/RSTA	night vision/reconnaissance, surveillance, and target acquisition

O

O&S	operations and support
OASA(ALT)	Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology
OCONUS	outside the continental U.S.
OCR	operational capability requirement
OCSW	Objective Crew-Served Weapon
ODCSOPS	Office of the Deputy Chief of Staff for Operations
OE	optoelectronic
OERC	Opto-Electronics Research Center (Korea)
OICW	Objective Individual Combat Weapon
ONERA	Office National d'Études et de Recherches Aerospatiales (France)
OPO	optical parametric oscillators
OPTEMPO	operational tempo
ORCA	Operational Requirement-Based Casualty Assessment
ORD	operational requirements document
OSD	Office of the Secretary of Defense
OTM	on the move

P

P^3I	preplanned product improvement
PAA	phased-array antenna
PAC3	Patriot Advanced Capability 3
PAM	precision attack munitions
PAPAGENA	Programming Environment for Applications of Parallel Genetic Algorithms
P_c	probability of classification
PCS	personal communications system
P_d	probability of detection
PDA	personal digital assistant
PEM	plastic-encapsulated microcircuit; proton exchange membrane
PEO	program executive officer
PERSCOM	Personnel Command
PET	positron emission tomography
PGMM	Precision-Guided Mortar Munition
P_h	probability of hit
P_i	probability of incapacitation
P_{ID}	probability of identification
P_k	probability of kill
PM	powdered metal; program manager
PO	project office
POC	point of contact; proof of concept
POL	petroleum, oil, and lubricants

POM	Program Objective Memorandum
POSTECH	Pohang University of Science and Technology (Korea)
POTS	plain old telephone service
PP&T	personnel performance and training
PROCOULD	Processing of Trace Constituents in Clouds over Europe
PTC	Paint Technology Center

Q

QoS	quality of service

R

R&D	research and development
RAMM	Responsive Accurate Munition Module
RAP	radio access point
RBV	Rapid Battlefield Visualization
RDA	research, development, and acquisition
RDC	research and development center
RDEC	research, development, and engineering center
RDT&E	research, development, test, and evaluation
RDX	cyclotrimethylenetrinitramine; rapid detonating explosive
ReformD	reforming diesel to refuel soldiers
REST	Rotorcraft Enhanced Survivability Technologies
RF	radio frequency
RFCM	radio frequency countermeasures
RFPI	Rapid Force Projection Initiative
RIB	rapidly installed breakwater
RIVM	National Institute of Public Health and the Environment
RML	*Revolution in Military Logistics*
RNA	ribonucleic acid
ROC	Republic of China
ROIC	readout integrated circuit
ROK	Republic of Korea
ROSA	Rotorcraft Open Systems Avionics
RPA	rotorcraft pilot's associate
RPV	remotely piloted vehicle
RRAPDS	Remote Readiness Asset Prognostics and Diagnostics System
RRS	roll rate sensor
RSTA	reconnaissance, surveillance, and target acquisition
RTI	run-time infrastructure
RTV	rapid terrain visualization
RWC	Real-World Computing program (Japan)
RWST	Rotary-Wing Structures Technology
RWV	rotary-wing vehicle

S

s	second
S&T	science and technology
S/W	software
SAALB	survivable armed reconnaissance on the digital battlefield
SAASM	Selective Availability Antispoofing Module
SADARM	sense and destroy armor
SAFF	safing, arming, fuzing, and firing
SAFOR	semiautomated forces
SAM	surface-to-air missile
SAR	synthetic aperture radar
SAS	Situational Awareness System
SATCOM	satellite communications
SBCCOM	Soldier and Biological Chemical Command
SBIRS	Space-Based Infrared System
SciDAR	Scintillation Detection and Ranging
SDD	system development and demonstration (formerly EMD)
SEB	staphylococcal enterotoxin B
SEDRIS	synthetic environment data requirements interchange specification
SEEDS	Synthetic Environment Evaluation and Demonstration Site
SEI	specific emitter identification
SEP	soldier enhancement program
SER	system evolution record
SERAT	structurally embedded reconfigurable antenna technology
SERC	Science and Engineering Research Council (United Kingdom)
SERDP	Strategic Environmental Research and Development Program
SHF	super high frequency
Shp	shaft horsepower
Si	silicon
Si_3N_4	amorphous silicon nitride
SiC	silicon carbide
SICCAS	Shanghai Institute of Ceramics (China)
SICS	Swedish Institute of Computer Science
SIGINT	signals intelligence
SIL	system integration laboratory
SIMOX	separation by implantation of oxygen
SINCGARS	single-channel ground and airborne radio system
SLID	small low-cost interceptor device
SLOC	software lines of code
SMA	shape memory alloy
SMART	Simulation and Modeling for Acquisition, Requirements, and Training
SMDBL	Space and Missile Defense Battle Laboratory
SMDC	Space and Missile Defense Command
SMS	signature management system
SNPE	Société National des Poudres et Explosifs (France)
SOA	Special Operations aircraft
SOCOM	Special Operations Command
SOF	Special Operations Forces
SOI	silicon on insulator
SPM	systems performance model
SRA	Strategic Research Area
SRBM	short-range ballistic missile
SRO	Strategic Research Objective

SSCN	Smart Sensor Communications Network
SSES	Suite of Survivability Enhancement Systems
SSHCL	Solid-State Heat Capacity Laser
SSM	soldier system modeling
STAB	stabilized agile beams
STARS	Software Technology for Adaptable, Reliable Systems
STD	seeker trade study
STIRR	Subsystem Technology for Infrared Reduction
STO	Science and Technology Objective
STOW	synthetic theater of war
STRICOM	Simulation, Training, and Instrumentation Command
STRV	Space Technology Research Vehicle
STS	seeked trade study
SUO	small-unit operations
SUSOPS	sustained operations
S/W	software
SWIR	short-wavelength infrared

T

T&E	test and evaluation
TACMS	Tactical Missile System
TACOM	Tank–automotive and Armaments Command
TARDEC	Tank–automotive Research, Development, and Engineering Center
TATB	triamino–trinitro–benzine
Tb	tetrabit
TCP	transmission control protocol
TD	technology demonstration
TDA	technology development approach
TEC	Topographic Engineering Center
TEED	tactical end-to-end encryption device
TEMO	training, exercises, and military operations
TERM	Tank Extended-Range Munition
TES	tactical engagement simulation
TFXXI	Task Force XXI
Ti	titanium
TIC	toxic industrial/agricultural chemical
TIME	Totally Integrated Munitions Enterprise
TM	tactical missile
TMAS	Tank Medium-Caliber Armament System
TNO–FEL	Organization for Applied Scientific Research—Physics and Electronics Laboratory (Netherlands)
TNO–PML	Organization for Applied Scientific Research—Prins Maurits Laboratory (Netherlands)
TNT	trinitrotoluene
TOC	tactical operations center
TOW	tube-launched, optically tracked, and wire-guided missile
TPSO	theater precision strike operations
TRACER	Tactical Reconnaissance Armored Combat Equipment Requirement
TRADOC	Training and Doctrine Command
TRL	technology readiness level
TRR	technology readiness review
TSM	TRADOC system manager
TTCP	The Technical Cooperation Program
TTP	tactics, techniques, and procedures
TWS	thermal weapon sight

U

UARC	university-affiliated research center
UAV	unmanned aerial vehicle
UBM	Universitat der Bundeswehr Munchen (Germany)
UGS	unattended ground sensor
UGV	unmanned ground vehicle
UHF	ultra high frequency
U.K.	United Kingdom
ULCANS	Ultra-Lightweight Camouflage Net System
USAAVNC	U.S. Army Aviation Center
USACE	U.S. Army Corps of Engineers
USAFACS	U.S. Army Field Artillery Center and School
USAIS	U.S. Army Infantry School
USAMRICD	U.S. Army Medical Research Institute of Chemical Defense
USAMRIID	U.S. Army Medical Research Institute for Infectious Diseases
USARIEM	U.S. Army Research Institute of Environmental Medicine
UV	ultraviolet
UWB	ultra wideband
UXO	unexploded ordnance

V

V	volt
V&V	verification and validation
Vdc	volts direct current
VGART	Variable Geometry Advanced Rotor Technology
VHF	very high frequency
VITD	vector interim terrain data
VR	virtual reality
VRI	virtual reality interface
VTOL	vertical takeoff and landing

W

W	watt
WAM	Wide Area Mine
WASPP	wafer-applied seal for PEM protection
WEBS	Warrior Extended Battlespace Sensor
WES	Waterways Experiment Station
Wh	watt-hour
WHO	World Health Organization
WIDA	weather impacts and decision aids
WIN–T	Warfighter Information Network—Tactical
WMD	weapons of mass destruction
WMO	World Meteorological Organization
WPSM	warfighter physiological status monitor
WRAIR	Walter Reed Army Institute of Research

WRN	wideband radio networking
WRNT	Wideband Radio Network Testbed
WSMR	White Sands Missile Range

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